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The distant quasar, ULAS J1120+0641, depicted in this artist's conception contains a supermassive black hole.

ESO/M. KORNMESSER

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Everything you need to know about the universe this month: a mysterious radio source baffles scientists, two stars kick up dust, a planetary system gets the vapors, and more.

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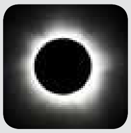

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FROM THE EDITOR

Those crazy quasars

Mysteries up until the late 1980s, quasars are the highly energetic centers of young galaxies. Like the one shown in this illustration, 3C 279, they harbor supermassive black holes. ESO/M. KORNMESSER

Sixty years ago, astronomers stumbled into a great mystery. Working at Caltech, Maarten Schmidt was busily studying the spectra of various radio sources scattered across the sky. In 1963, he employed the largest telescope in the world at the time, the 5m Hale Telescope at Palomar Mountain Observatory, to capture an image of a visible counterpart to one of his curious radio sources. It was identified as 3C 273 in the constellation Virgo, the nomenclature relating it to the *Third Cambridge Catalog of Radio Sources.*

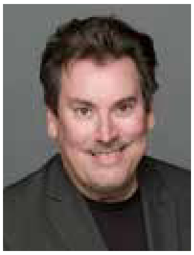
Soon Schmidt realized the puzzlement of his discovery. This very energetic radio source was extremely distant — some 2.4 billion light-years away — but very "loud" in energy output. How could this be? Something strange was going on. He categorized 3C 273 and similar discoveries like 3C 48 and others as quasi-stellar objects, or quasars for short.

This month, on the anniversary of that discovery, Contributing Editor Rich Talcott gives us the full story of quasars on page 16. As years passed from the initial discovery, into the 1980s, the mystery of distant, energetic objects deepened. Other types of high-energy objects came to the fore. There were BL Lacertae objects, Seyfert galaxies, and other types of objects that astronomers placed in the "astronomical zoo."

Long story short, it finally became clear that these weird, high-energy denizens all represented objects with powerful central black holes. Rich provides all the details, and in a companion story on page 24, describes how you can observe 3C 273, the brightest quasar in the sky, for yourself. Enjoy.

Yours truly,

David J. Eicher
Editor



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ONE OF THE BEST PLACES TO WATCH THE TOTAL SOLAR ECLIPSE

Evansville, IN is in the path of totality and has great things planned to celebrate

On April 8, 2024, a total solar eclipse is coming! One of the best places to observe this natural phenomenon is Evansville, IN. This charming city, located on a scenic bend of the Ohio riverfront, has a small-town vibe with big-time energy, making it the perfect host for this historic astronomical event.

Evansville is a great place to visit any time – it has everything you want in a vacation: historical sites, world-class dining, posh hotels, and abundant shopping. The eclipse will be an especially opportune time to take a trip. The city has many great things planned. The University of Southern Indiana is hosting Solarpalooza, a free, multi-day event beginning Sunday, April 7th, with a speech from retired NASA astronaut Joan Higginbotham, followed by a day of experiential learning. The university's 1,400 acres will allow for unobstructed sky views during the eclipse, which will last three minutes around 2:02 p.m.

Another way to experience the eclipse is at Angel Mounds State Historic Site, which is one of the best-preserved Native American sites in North America. During your eclipse experience, connect with the ancient wisdom of the stars while museum experts guide you through the cosmic and historical alignments of the site.

While in town for this historic event, take the opportunity to discover the heartbeat of the city. Explore Evansville and enjoy fine shopping, eclectic restaurants, a range of accommodations (including some in more rural settings), live music festivals, and a happening nightlife scene.

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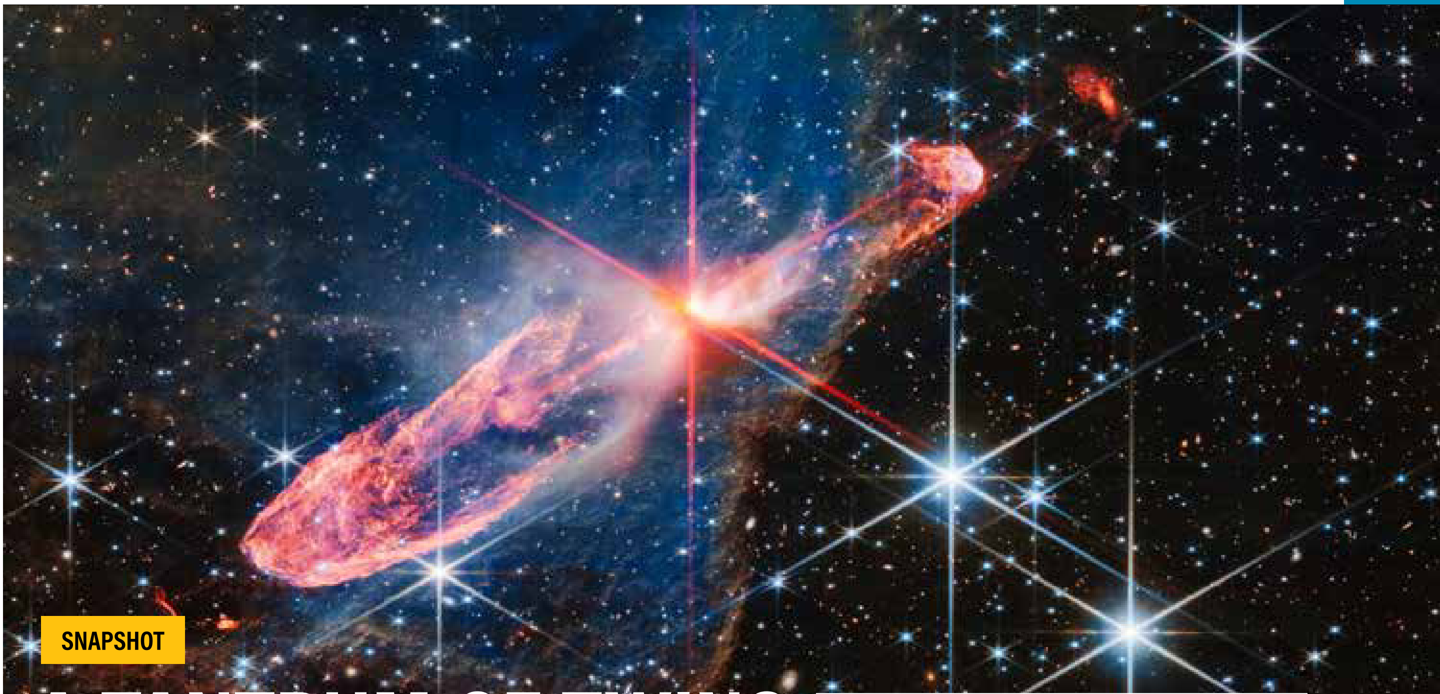

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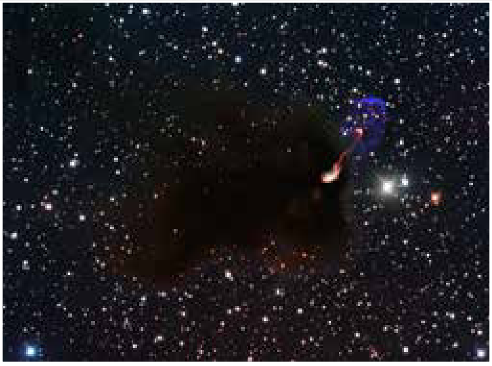


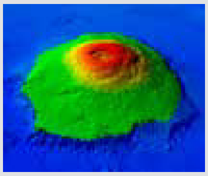
Two young stars kick up a storm.

NASA's James Webb Space Telescope (JWST) has cast its gaze upon Herbig-Haro 46/47, which lies 1,400 light-years away in Vela. The designation refers to the two jets of gas that are being spat out by two rambunctious young stars at the center of the orange diffraction spikes. The still-forming stars are surrounded by a dusty disk, which is not visible; however, it casts conical shadows above and below. But perhaps the most impressive details are those seen in the nebulous blue cloud that surrounds the jets. This cloud is an example of a Bok globule, and when viewed at optical wavelengths (as in the inset ground-based image), it appears as a pitch-black droplet of cold dust. JWST's infrared vision can reveal fine, wispy details in these dense clouds from which young stars condense. —MARK ZASTROW

IMAGE: NASA, ESA, CSA; IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI), ANTON M. KOEKEMOER (STSCI), INSET: ESO/BO REIPURTH. BOTTOM FROM LEFT: NASA, ESA, CSA, JOSEPH OLMSTED (STSCI); A.HILDENBRAND/GEOPS/CNRS (IMAGE PRODUCED FROM MOLA PUBLIC DATA); ESO

» HOT BYTES

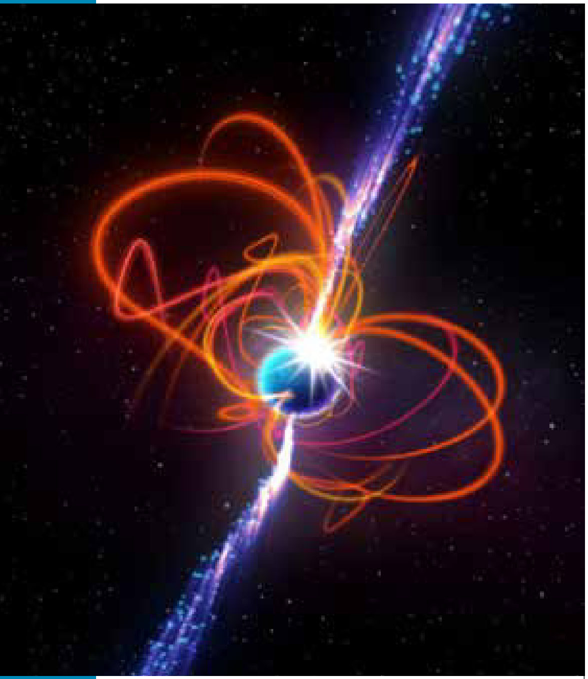
STELLAR SAUNA
JWST has detected water vapor in the inner disk of the nascent planetary system PDS 70. The find indicates that any rocky planets currently forming have immediate access to water that could seed oceans.



LOST ISLAND
The extinct martian volcano Olympus Mons may have been a volcanic island in a vast sea 3 billion years ago. A study found that the mountain's slopes share morphological similarities with volcanic islands on Earth, where lava solidifies when it meets the sea.

HALFWAY THERE
The construction of the Extremely Large Telescope is 50 percent complete, the European Southern Observatory said July 11. The 39-meter telescope in Chile is slated to begin operations in 2028 as the first of the next generation of extremely large ground-based observatories.

RARE RADIO SOURCE STUMPS ASTRONOMERS



MYSTERY OBJECT. The strange body sending slow radio signals might be a unique type of magnetar — a highly magnetic, rotating neutron star. ICRAR

Magnetar, white dwarf, or something else entirely?

That's the question astronomers have after finding a star that doesn't quite fit any known category.

A team of astronomers identified this object last year using the Murchison Widefield Array in the outback of Western Australia. Called GPM J1839-10, it lies 15,000 light-years away within the constellation Scutum.

Originally, the team thought of it as a magnetar — a rare type of neutron star with a powerful magnetic field that sends energy into space as it spins. Nearly all other known magnetars have brief periods ranging from a few seconds to a few minutes. But this object produces powerful five-minute-long bursts of radiation every 21 to 22 minutes, which would make it the longest-period magnetar ever detected, and raises questions about how magnetars form and evolve. The team reported their results July 19 in *Nature*.

"The universe still has the capacity to surprise us," says Natasha Hurley-Walker, the study's first author and an astrophysicist at Curtin University in Perth, Australia.

There are only a dozen known magnetars, and astronomers still don't know the specific conditions that create magnetars versus run-of-the-mill neutron stars. Magnetars typically emit radiation in high-energy X-rays rather than lower-energy radio waves. However, "a very small number of magnetars have been known to produce radio waves for a few weeks to months," Hurley-Walker notes.

Puzzlingly, GPM J1839-10 seems to exhibit the opposite traits. Its five-minute radio pulses are remarkably consistent — archival data from the Very Large Array reveal it's been emitting them since at least 1988. But when the team looked for X-rays, they couldn't detect any. Magnetars are "supposed to generate bright X-ray bursts," says Hurley-Walker, "either just before or with the radio pulses."

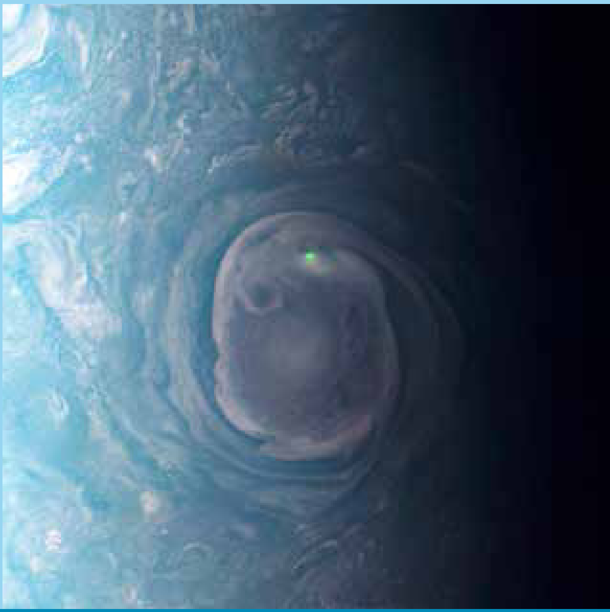
Furthermore, given its 22-minute period, GPM J1839-10 should be spinning too slowly to produce radio waves — yet it's clearly doing so. These characteristics make it a little harder to believe that this object is a magnetar. If it is, Hurley-Walker's team suspects it's a special type of magnetar whose emission is powered by a twisted magnetic field.

Alternatively, GPM J1839-10 could be a strange, highly magnetic white dwarf, the leftover core of a Sun-like star. Such objects have weaker magnetic fields than neutron stars. White dwarfs are also larger than neutron stars and thus spin more slowly, which could explain GPM J1839-10's long period.

Of course, there's a third scenario: GPM J1839-10 could be an entirely new object never before seen in the skies.

The answer is still a toss-up. Hurley-Walker says she has polled world experts in transient radio astronomy on those three possibilities, and "the room was just split," she says. "Not just observers but also theorists and people were like, this just breaks all the rules. It's why it's such an exciting result." —ELIZABETH GAMILLO

Jove's bolt from the blue



Lightning flashes (green) in the midst of a vortex near Jupiter's north pole in this image captured by NASA's Juno mission as it made a close flyby of our solar system's largest planet on Dec. 30, 2020. The craft was about 19,900 miles (32,000 kilometers) above the gas giant's ammonia-filled cloud tops. Some of Jupiter's lightning results from interactions between falling water-ammonia droplets and updrafts of water-ice crystals; the collisions of particles build up static charge, which discharges as lightning. —M.Z.

IMAGE DATA: NASA/JPL-CALTECH/SWRI/MSSS; IMAGE PROCESSING BY KEVIN M. GILL © CC BY

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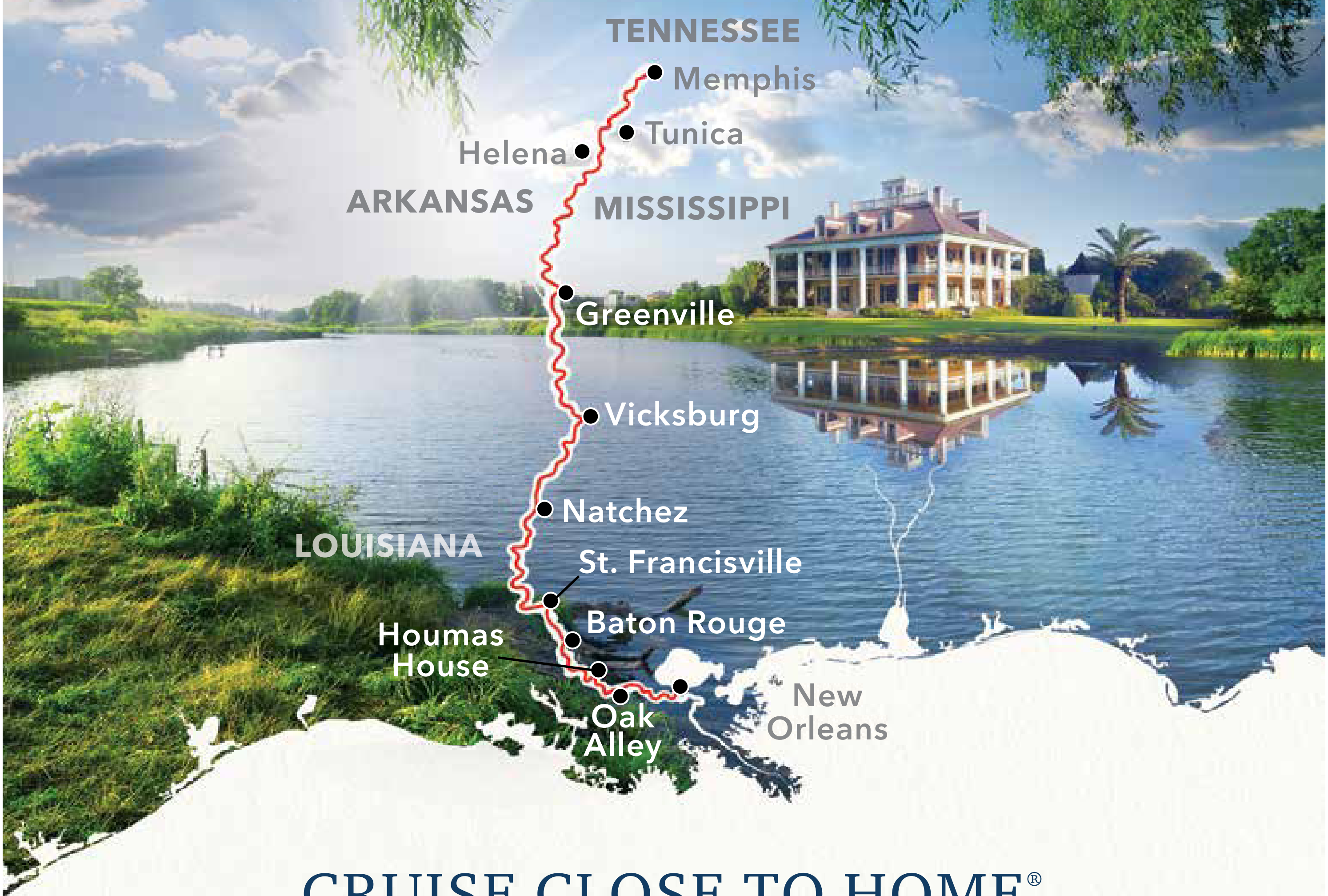

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Hot Jupiters may not have migrated

CLOSE TO HOME. New evidence suggests that some hot Jupiters may form close to their stars in the locations where we observe them, not migrate there after forming. ESA/ATG MEDIALAB, CC BY-SA 3.0 IGO

THE STORY OF HOW hot Jupiters form may have to be rewritten.

Hot Jupiters are gas giant exoplanets similar to Jupiter but orbiting close to their host stars. When they were first discovered, astronomers thought these planets must form farther out in their systems, where cooler gas and dust can accumulate. Their close-in locations can be explained by chaotic orbital dynamics that allow them to migrate inward, kicking smaller planets out of the system with their gravitational bulk like a schoolyard bully. This seems in keeping with the majority of observational data, which shows that many such systems do not contain smaller planets orbiting alongside the giants.

However, a new analysis of the data from NASA's Kepler planet-hunting mission suggests this isn't always the case: Somewhere between 6 to 18 percent of hot Jupiters *do* have other planets nearby. "Our research shows that at least a fraction of hot Jupiters cannot form through a violent process," said study leader Songhu Wang, an astronomer at Indiana University in Bloomington, in a statement. Wang presented the work at the 2023 summer meeting of the American Astronomical Society.

Kepler, which was retired in 2018, searched for planets using the transit method, waiting for stars to temporarily dim as planets cross in front of them. Wang and his colleagues used a secondary technique to search for planets near hot Jupiters: They looked across four years of data from Kepler to see if the precise timing of the hot Jupiters' transits varied. If planets were lurking nearby, they may not transit, but their gravitational pull could cause the hot Jupiter to transit slightly earlier or later on each orbit.

A similar analysis from over a decade ago of the first 1.5 years of Kepler data had not uncovered any such planets. But by going back to the full dataset from the craft's original mission, Wang and his team had better luck: Out of 101 hot Jupiters discovered by Kepler, they found 16 were accompanied by nearby planets.

The work is not the first to suggest that hot Jupiters can form *in situ*, close to their stars. In 2018, Caltech astronomers Elizabeth Bailey and Konstantin Batygin argued that the orbits of hot Jupiters tend to cluster outside of a minimum distance from their star, lacking the amount of randomness that would be expected if most hot Jupiters migrated inward. — NICK OAKES

QUICK TAKES

MIRROR WORLD

The exoplanet LTT9779 b reflects 80 percent of the light that falls onto it from its host star, according to observations from the European Space Agency's Cheops mission. Its shininess is due to glassy, metallic clouds made of silicates mixed with metals like titanium.

DUSTY UNIVERSE

Data from the James Webb Space Telescope (JWST) indicate carbon-rich dust appeared in galaxies less than 1 billion years after the Big Bang — sooner than current theories of dust formation predict.

A NEW COSMIC RULER

Like light, gravitational waves' trajectory can be bent, or lensed, by the presence of massive objects like galaxies. Future gravitational-wave observatories could use such lensed sources to measure the expansion rate of the universe, scientists have proposed.

DEMOLITION DERBY

An unusual gamma-ray burst detected in 2019 from an ancient galaxy did not have a supernova, researchers report. It appears the burst was caused by two compact stars in the galaxy's crowded core randomly running into each other.

METHANE MILESTONE

The private Chinese firm Landspace's Zhuque-2 became the first methane-fueled rocket to reach orbit July 12, following failed attempts from Relativity Space's Terran 1 and SpaceX's Starship earlier this year. Methane is cleaner, safer, and cheaper than existing fuels like kerosene.

DARK STARS?

A team of astronomers has proposed that some of the unexpected galaxy candidates observed by JWST in the early universe may instead be dark stars — stars made mostly of normal gas but powered by annihilating dark matter particles instead of nuclear fusion. — M.Z.

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ALAN DYER

Astronomy beginners are often obsessed with power — meaning magnification. I sure was. But I quickly learned that high power amplifies the air's blurriness and takes away the wide field that many objects require for maximum impressiveness.

After recovering from highpoweritis, one is unlikely ever to succumb to it again. Like many, I went too far in the other direction and avoided using high magnification even when doing so would boost contrast and bring out previously unseen detail.

The usual rule, based on Dawes' limit (which determines a telescope's maximum resolving power), is that the upper useful magnification is 50x for each inch of a telescope's aperture. So, my 12.5-inch f/6 reflector theoretically could handle up to 625x and my smaller 5-inch Takahashi refractor 250x. Yet I routinely merely use wide-field 100x eyepieces on a binoviewer on my Takahashi. Here in the Appalachians, that's usually the *actual* upper limit of clear viewing given our typical seeing conditions, which are comparable to the quality of astronomical observing achievable from the surface of Venus.

Sometimes I pathetically try to further steady the images by using extremely low power, meaning binoculars. This leads into this month's topic: the ultimate in stable viewing. We're talking zero magnification — viewing objects with the naked eye. No added magnification whatsoever.

Is there any rational reason to do this? Absolutely! Having led astronomy tours for the past 30 years, I've carefully watched what impresses people. It's true that showing them far-southern wonders, like the Tarantula Nebula and 47 Tucanae, through a 25-inch instrument under desert skies is about as good a celestial experience as one can have. But just as wonderful is merely viewing the Milky Way from any unpolluted, wide-open site. Each year, I have a group under perfect skies put their backs to the Milky Way and wave their arms. All their lives they'll tell skeptical people how they saw their own shadow by the Milky Way's light!

On the web, Milky Way images have appeared more and more frequently this past decade. Usually the brightest portion is depicted — the summer Milky Way centered on Sagittarius. You can always see Antares to its right and, a bit farther right still, the arachnid's distinctive claws, composed of the near-vertical line of Beta (β), Delta (δ), and Pi (π) Scorpii. All these can be enjoyed for yourself without any equipment.

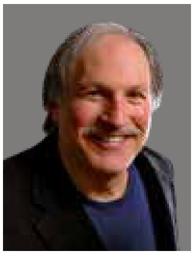
The most sensational celestial events also demand zero extra magnification. You won't see the northern lights if you use a telescope. Nor will you enjoy a meteor shower. My solar eclipse preference is to spend half of totality observing with no equipment, to avoid neglecting the eerie lighting on the surrounding countryside, and the other half using stabilized binoculars.

But it's not just beauty that's involved here. Before 1608, when Hans Lippershey and others invented the telescope, many observers made profound celestial discoveries using their eyes alone. In the third century B.C., Aristarchus carefully noted the size of Earth's shadow on the Moon during lunar eclipses. He also determined that the half-illuminated Moon was not positioned exactly 90° from the Sun. These observations let him conclude, among other things, that the Sun must be larger than Earth. And since it made more sense to him that a smaller object should orbit around a larger one, he concluded — more than 1,700 years ahead of Copernicus — that Earth circles the Sun while spinning on its own axis.

The very best magnification may often be zero.

Even by noticing that night is dark, you'll correctly conclude that either the cosmos cannot have an infinite number of stars, or it must be too young for most starlight to have had time to reach us. (Turns out, both are true.) Huge takeaways, using no instrumentation.

So, whether your goal is to explore science, beauty, or even some of the mind-stretching areas of metaphysics and philosophy, the very best magnification may often be zero.



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

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A topsy-turvy eclipse

Find out what made this hybrid solar eclipse a one-of-a-kind event.

The author's photo-illustration attempts to capture the unusual appearance of totality, as seen during the April 20, 2023, hybrid solar eclipse near Com, East Timor. STEPHEN JAMES O'MEARA

BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

Like fingerprints, no two hybrid solar eclipses are the same. Many share general features, such as the solar corona, prominences, chromosphere, and more. But how these phenomena will appear to the naked eye during any given eclipse is anyone's guess. The hybrid solar eclipse of April 20, 2023, was a stunning reminder of just how visually surprising an eclipse can be.

No two hybrid solar eclipses are the same.

My wife and I observed totality near Com, East Timor, close to the point of maximum eclipse (a total of 76 seconds). During past eclipses, I could perceive changes in the ambient light when the Sun was approaching 50 percent eclipsed. However, as this eclipse reached 75 percent totality and the quality of light turned ashen, I still couldn't perceive these changes. I wondered if this had to do with the Sun's altitude (70°).

The temperature was roughly 90 degrees Fahrenheit (32 degrees Celsius) and began dropping during the partial phases. The strong winds we had at the start of the eclipse stopped completely; although I have felt breezes diminish during past events, the abrupt quenching of these strong gusts felt preternatural.

A remarkable event occurred a full two minutes before totality, when extremely high-contrast shadow bands — thin, wavy lines caused by Earth's turbulent atmosphere refracting sunlight immediately before and after a total solar eclipse — rippled across the terrain from the southwest (214° azimuth) to the northeast (30°) at a steady pace. The bands were about a foot apart and intense enough to show on a video made with an ancient iPhone 5s. Equally peculiar, the bands appeared most prominently when seen against the sandy, rocky terrain.

A total surprise

While the initial diamond ring phenomenon was prolonged, few if any Baily's beads stood out prominently in the seconds before totality. During this time, the Moon's disk shone forth with a distinct shade of purple. This rich color was seen against a pale seafoam green inner corona. Never at any other eclipse had I seen these colors so noticeably and comfortably with the unaided eye.

Then, just as the Moon slammed the door on the last crescent of sunlight, five brilliant coronal streamers, sharp and white, shot out radially from pale petals beyond the plum Moon in a starfishlike fashion. An irregular crescent of chromosphere (the layer of the Sun just above the visible surface) hugged the Moon's limb, which also revealed several naked-eye prominences (giant loops of plasma arcing off the Sun's surface). The largest coronal streamer burned pink, adding to the already stunning array of color.

As totality progressed, the Moon darkened, but not to the usual inky black. Additionally, the equatorial "butterfly wings" that are typically formed by coronal streamers (as they tend to flow most freely from the Sun's equator) did not appear. The only other corona appeared as a breath of diffused light extending perhaps one solar radius from the disk. During totality, the sky did not completely darken. It remained a pale blue, akin to that at the start of nautical twilight. At third contact, with the appearance of the second diamond ring, intense shadow bands returned, lasting another two minutes. The last topsy-turvy event occurred several minutes after totality, when some cows that had been lingering unaffected before and during totality suddenly herded and left for home in single file.

On reflection, I believe the color and glamour of the visual details were due to the fact that the contrast between the corona (about the brightness of a Full Moon) and the sky was low. The difference was similar to seeing the Full Moon in the dark night sky versus in the twilight, when the eye does not suffer ill effects from glare.

These observations may be worth keeping in mind as we approach the April 8, 2024, total solar eclipse. It will be interesting to compare the brief nature of this hybrid event to a total solar eclipse lasting several minutes. As always, send your thoughts and observations to sjomeara31@gmail.com.

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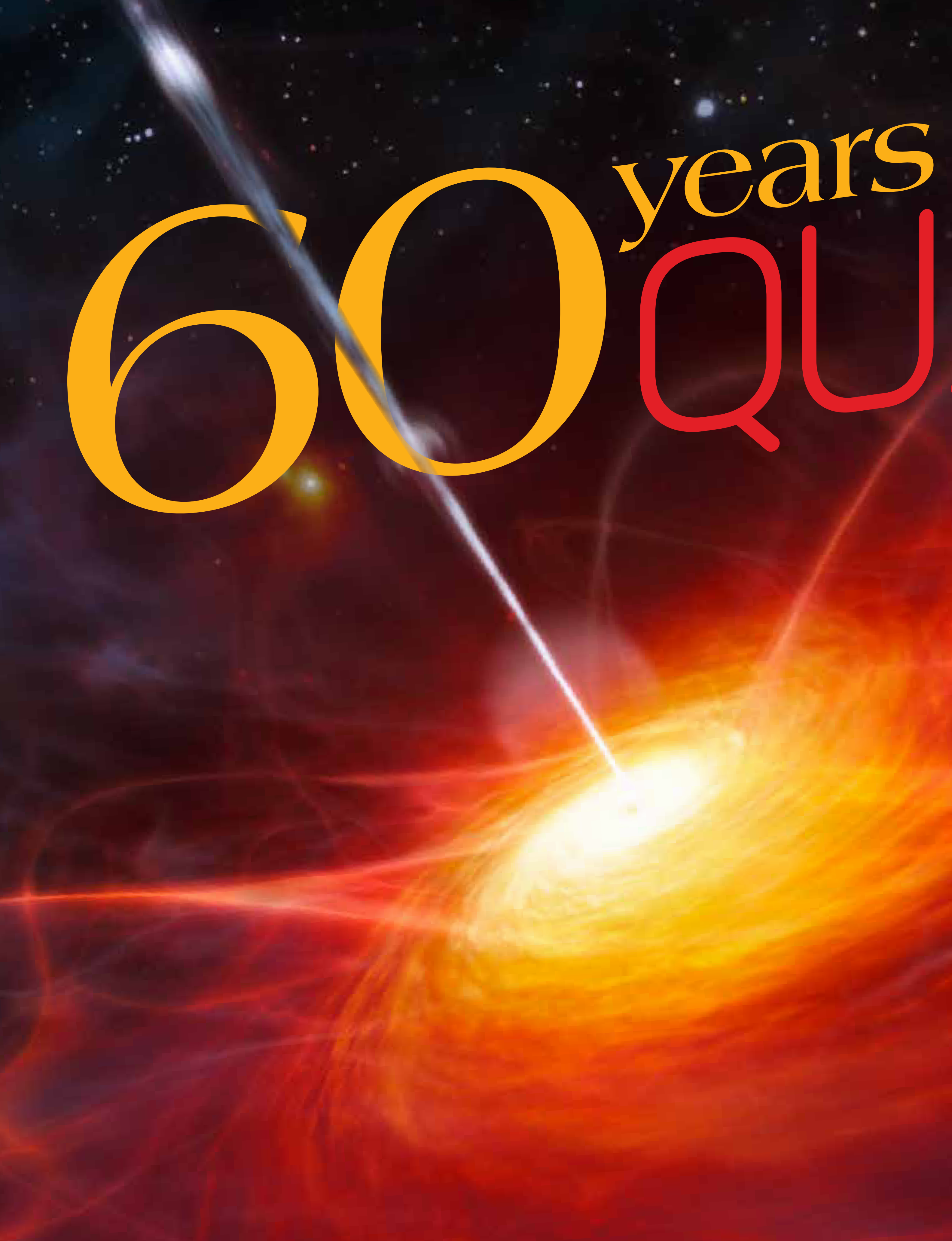


of
ASARS

These ravenous black holes in the hearts of distant galaxies are beacons from the early universe.

BY RICHARD TALCOTT

THE 1960s WERE A TIME of revolution. Antiwar rallies, civil rights marches, and political assassinations dominated the evening news, while radical advances in spaceflight culminated with the first humans landing on the Moon in July 1969.

Astronomy experienced its own ’60s revolution, as a trio of totally unexpected discoveries rocked the science world. In 1964, radio astronomers Arno Penzias and Robert Wilson discovered the fading afterglow of the Big Bang with a horn-shaped antenna at Holmdel, New Jersey, revealing the cosmic microwave background radiation. Then in 1967, Jocelyn Bell, working at the Mullard Radio Astronomy Observatory in Cambridge, England, detected the first pulsars — rapidly rotating neutron stars that some supernovae leave behind.

But before those two breakthroughs, quasars burst onto the scene in 1963. These strange objects looked like stars yet emitted more energy than entire galaxies. In the six decades since their discovery, astronomers have come to understand they are powered by supermassive black holes at the centers of galaxies. No longer mere curiosities, quasars serve as valuable probes, helping astronomers understand galaxy formation and evolution, as well as the earliest epochs of the universe.

Deep-space beacons

The first hints of quasars came in 1959, when the Third Cambridge (3C) Catalog of radio sources was released, featuring several oddball objects. The strangest were strong radio emitters that looked like stars; they were dubbed quasi-stellar radio sources. Normal stars, like the Sun, glow so dimly at radio wavelengths that researchers never expected to uncover radio-*loud* stars.

The mystery’s resolution came from the catalog’s 273rd entry: 3C 273. The Moon occulted this object several times in 1962, allowing radio astronomers to pinpoint its location. Caltech astronomer Maarten Schmidt targeted the source with the 200-inch

The distant quasar ULAS J1120+0641 depicted in this artist’s conception has a supermassive black hole with the mass of 2 billion Suns. It appears to us as it was just 770 million years after the Big Bang.

ESO/M. KORNMESSER

Hale Telescope, then the world's largest, and found what seemed to be an unremarkable 13th-magnitude star. But its spectrum was extraordinary. It showed a series of strong emission lines that didn't seem to correspond to any known element.

Schmidt's eureka moment came on Feb. 5, 1963, when he recognized the oddball lines as the spectral fingerprint of hydrogen — the universe's most common element — shifted from its normal wavelengths far to the red portion of the spectrum. This redshift implied 3C 273 was receding from Earth at nearly 16 percent the speed of light!

No star behaves like this. Schmidt quickly realized that 3C 273's redshift derived from the expansion of the universe, placing the object some 2 billion light-years from Earth. To appear as a 13th-magnitude object — bright enough to show up in modest amateur telescopes (see page 24) — 3C 273 must have a luminosity 40 times that of the brightest galaxies known at the time.

Schmidt and his Caltech colleague Jesse Greenstein immediately recognized that another quasi-stellar radio source, 3C 48, had an even higher redshift and lies well beyond 3C 273. A year later, Taiwanese-American astrophysicist Hong-Yee Chiu shortened "quasi-stellar radio source" to "quasar," and the name stuck.

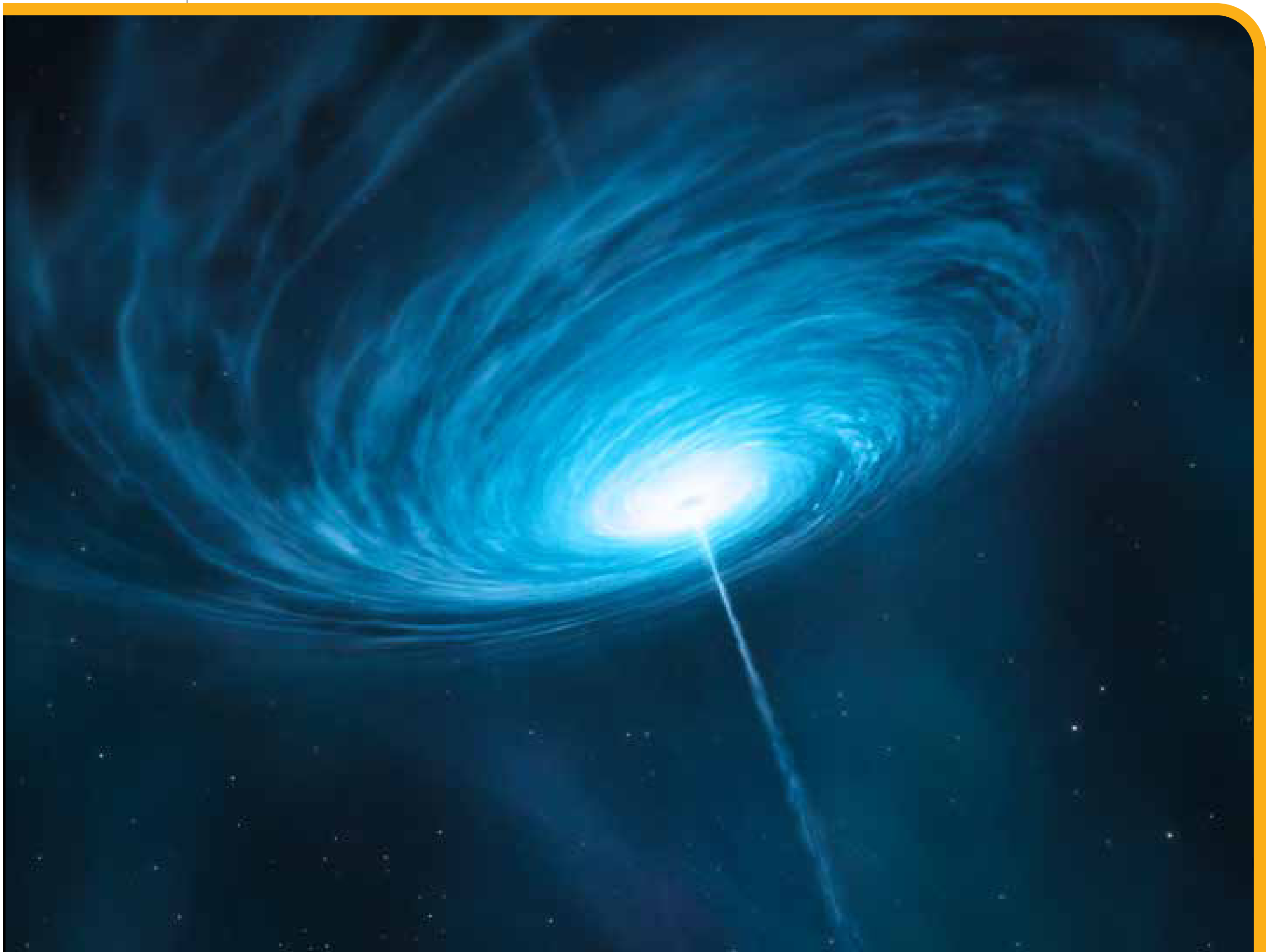
In the 60 years since, researchers have cataloged more than a million quasars. Oddly, only about 10 percent emit radio waves, but these radio-quiet quasars otherwise mimic their louder siblings.

From darkness, light

It quickly became apparent that quasars must tap into a previously unknown energy source. Not only do quasars appear starlike, but they also change brightness in periods as short as a day. Because no object can vary in less time than it takes light to cross it, this means some quasars are no bigger than a light-day across, or just a few times wider than Neptune's orbit around the Sun. And quasars radiate far more light from this tiny volume than entire galaxies.

Nuclear fusion, which powers the Sun and other stars, converts less than 1 percent of a star's mass into energy and can't come close

IT QUICKLY BECAME APPARENT THAT QUASARS MUST TAP INTO A PREVIOUSLY UNKNOWN ENERGY SOURCE.



3C 279, shown in this artist's concept, is a highly variable quasar that has gone through outbursts observed across the electromagnetic spectrum. ESO/M. KORNMESSER to the power quasars emit. The answer seemed incredible at the time: supermassive black holes containing millions or billions of times the Sun's mass at the centers of galaxies, actively feeding on surrounding stars and gas.

Although suggested in the mid-'60s, the idea didn't gain wide acceptance for a couple of decades because many scientists considered black holes purely theoretical. But astronomers now think that depending on the black hole's rotation rate, this process can convert up to 42 percent of the material's mass into electromagnetic energy.

A black hole's gravity is so strong that it can tear apart a star or gas cloud that ventures close. As the stripped material spirals toward the black hole's event horizon — the point of no return at which nothing, not even light, can travel fast enough to escape — it forms a flattened accretion disk. The gas swirls around at speeds approaching that of light. Friction among the atoms heats the gas so much that it produces the intense radiation we see.

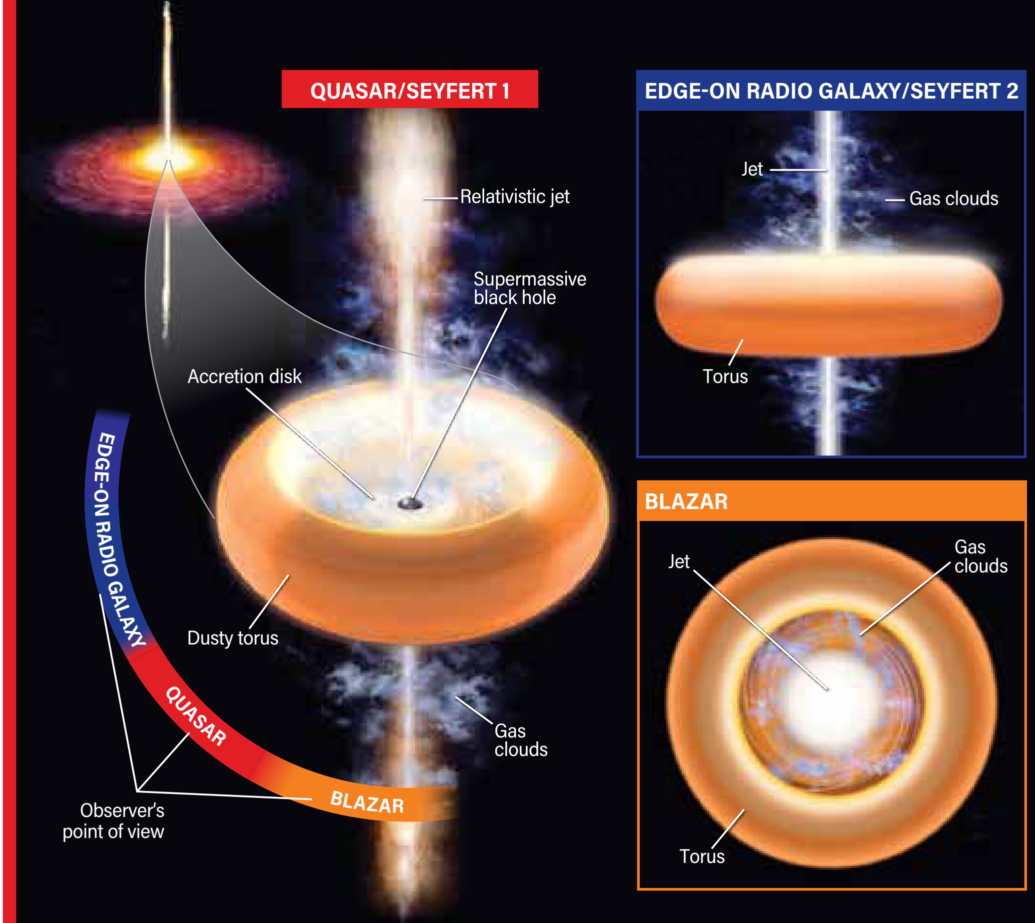
Closer to the black hole, where the atoms move faster and temperatures rise higher, the accretion disk emits mostly ultraviolet light. As temperatures dip farther out, the radiation comes out at lower-energy visible and infrared wavelengths. Most of the X-rays seem to emanate from a much larger corona of gas that envelops the disk. According to quasar expert William Keel of the University of Alabama, "Narrow [optical] emission lines come from low-density gas as it absorbs the ionizing ultraviolet light from the inner accretion disk and electrons recombine with the ions, rattling around and exciting additional ions by collisions along the way."

Accretion disks often amplify existing magnetic fields. "Around a black hole, the field lines passing through the accretion disk wind around as it rotates, creating a tunnel stretching away from the black hole perpendicular to the disk," says astrophysicist Belinda Wilkes, a visiting fellow in the School of Physics at the University of Bristol, U.K. "Charged particles trapped by the magnetic field move very fast along the field lines away from the black hole, forming bipolar jets that grow larger than the galaxy itself. The particles emit radiation in the radio, X-ray, and sometimes visible light parts of the electromagnetic spectrum."

We do not observe the quasar's electromagnetic radiation at the wavelengths it is initially emitted — cosmic expansion shifts them to the red. For relatively nearby quasars, the difference is dramatic but not extraordinary. For example, the lines 3C 273 emits appear 16 percent longer at Earth than at the quasar, reflecting the object's redshift of 0.16.

Most quasars lie much farther away. Their population peaks at redshifts between 2 and 3, meaning the observed wavelengths appear three to four times longer than the emitted wavelengths. This corresponds to objects that

AN ACTIVE GALACTIC ZOO



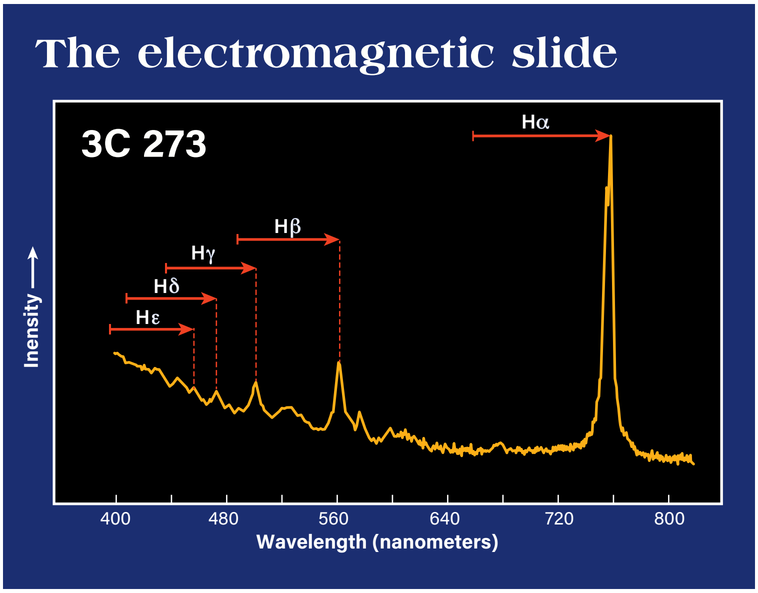
Quasars rightfully deserve a place in any list of astronomical oddities, but they are just one species in a menagerie of exotic beasts. Close relatives include blazars, radio galaxies, and two types of Seyfert galaxies. These cousins also feature central supermassive black holes actively feeding off their surroundings, though they appear to have less ferocious appetites than quasars.

Astronomers refer to all these objects as active galactic nuclei, or AGN. Although they were originally identified as separate types of objects, many astronomers now think that they are one type of object seen from different perspectives. In this simplified schematic of a unified model, blazars appear when we look straight down a jet to the black hole, while quasars are what we see when our view is slightly off-axis. Radio galaxies are viewed nearly edge-on, with their bright cores entirely shrouded by dust.

The central supermassive black holes at the center of the Milky Way and other nearby galaxies may enjoy an occasional snack, but they don't feast like AGN. — *R.T.*

The unified model of AGN holds that all types of AGN contain a fundamental set of components. From the inside out, these are: a supermassive black hole; an accretion disk and a hot corona of gas; a region of fast-moving gas, which produces wide emission lines; an obscuring torus of dust; and a slower-moving gas region, which produces narrower emission lines. Some AGN also sport powerful jets.

ASTRONOMY: ROEN KELLY


The electromagnetic slide

Astronomers couldn't make sense of the spectrum of 3C 273 until Maarten Schmidt realized that the expansion of the universe had shifted all the familiar emission lines to redder (longer) wavelengths. *ASTRONOMY*: ROEN KELLY, AFTER WILLIAM KEEL

existed some 3 billion to 2 billion years after the Big Bang and whose light has been traveling toward Earth for 10 billion to 11 billion years.

Giving feedback

In a laboratory on Earth, an electron's transition from one energy level to a lower one results in emission of a single photon at a precise wavelength. Nature proves messier. Observed emission lines spread out because enormous numbers of atoms radiate at the same time, and these atoms move with respect to Earth. The Doppler effect causes a photon emitted by material moving toward you to shift to a shorter wavelength (bluer light), while material moving away delivers light of longer wavelengths (redder light).

The smeared emission lines from a quasar's accretion disk thus carry vital information: The lines' widths reveal how fast the gas rotates around the black hole. And once astronomers know how long it takes the material to orbit the central black hole, they can calculate its mass.

One of the key discoveries in the early years of the 21st century is that most large galaxies possess central supermassive black holes. Even more intriguing, the mass of the black hole seems to correlate with the mass of the host galaxy's bulge — even though the bulge typically outweighs the black hole by a factor of 500 to 1,000.

Scientists find such correlations compelling evidence that the growth of central black holes influences the growth of galaxies. "Most people think they both grow because they tap into common reservoirs of matter — the interstellar gas in a galaxy," says Keel. "As gas enters the galaxy and cools, some forms stars and some, less directly, falls close enough to the core to feed the supermassive black hole."

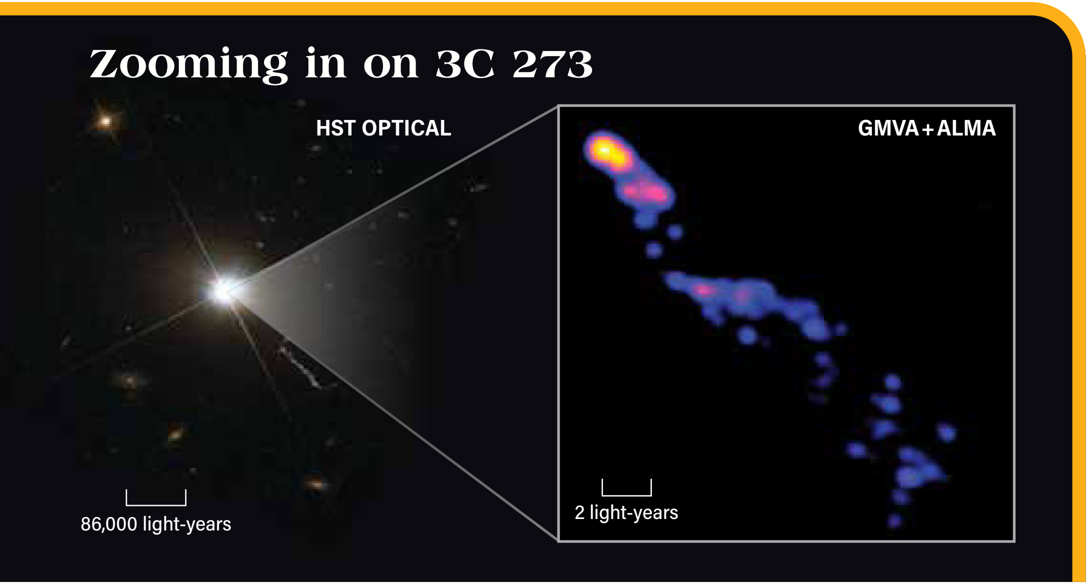
But the black hole doesn't swallow everything. "Although some of the infalling matter falls into the black hole and feeds its growth and activity, the rest streams out along the jets back into and through the galaxy," says Wilkes. "This combination of inflow and outflow connects the evolution of the black hole with that of its host galaxy in a feedback loop."

The connection between galaxy and black hole only grows over time. "Galaxy mergers are common and imply that the black holes will eventually merge as well," says Keel, meaning that the masses of both galaxies and their black holes will grow. So even if there is no relationship between the mass of a black hole and its galaxy to begin with, as they merge with others many times over, a correlation will emerge.

Lighting the cosmos

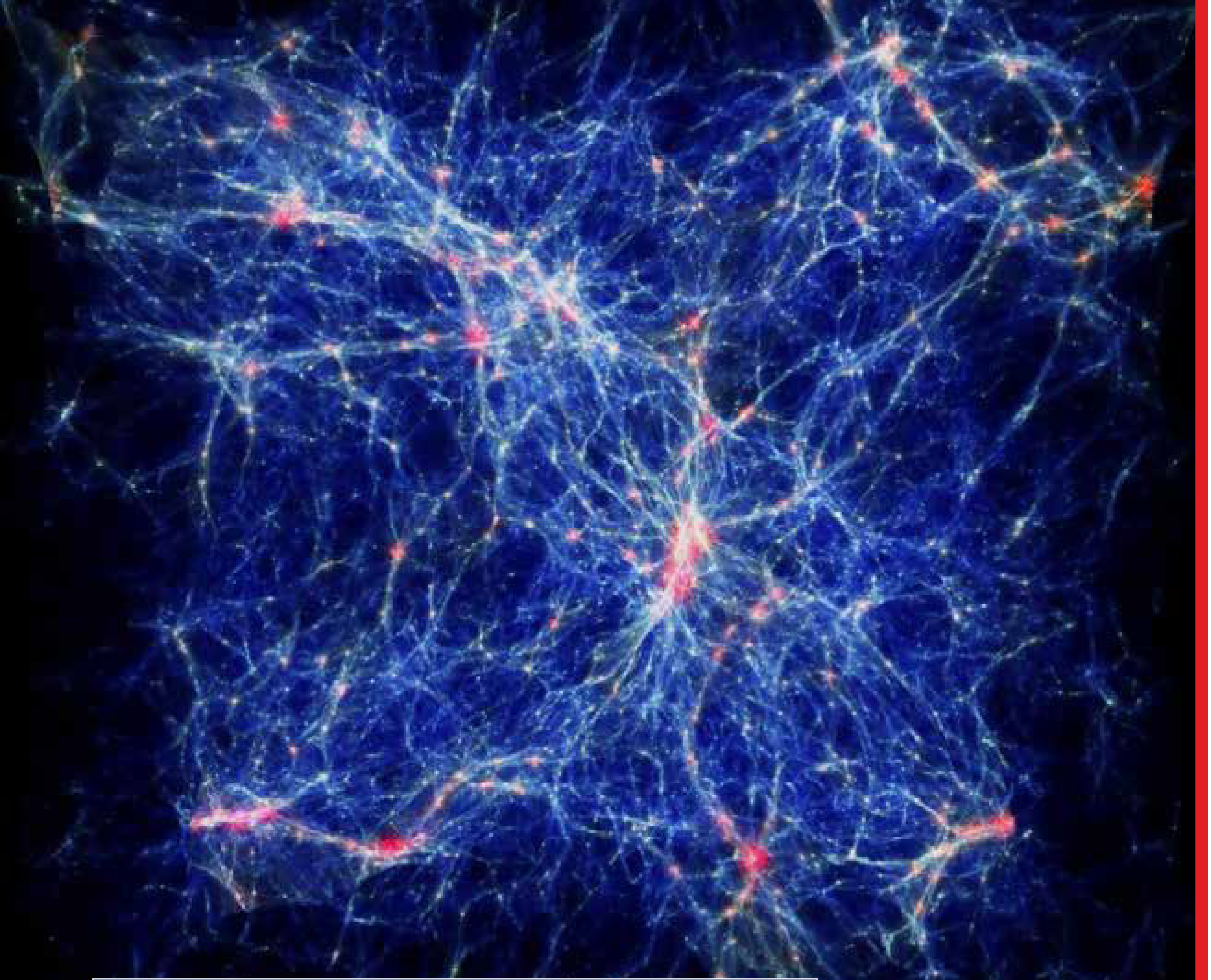
With the exceptions of fleeting events like supernovae and gamma-ray bursts, quasars are the brightest objects in the universe. This makes them powerful probes of the distant universe. And because photons from these objects take so long to reach us, they also shed light on conditions when the cosmos was younger.

Once astronomers started finding quasars with redshifts greater

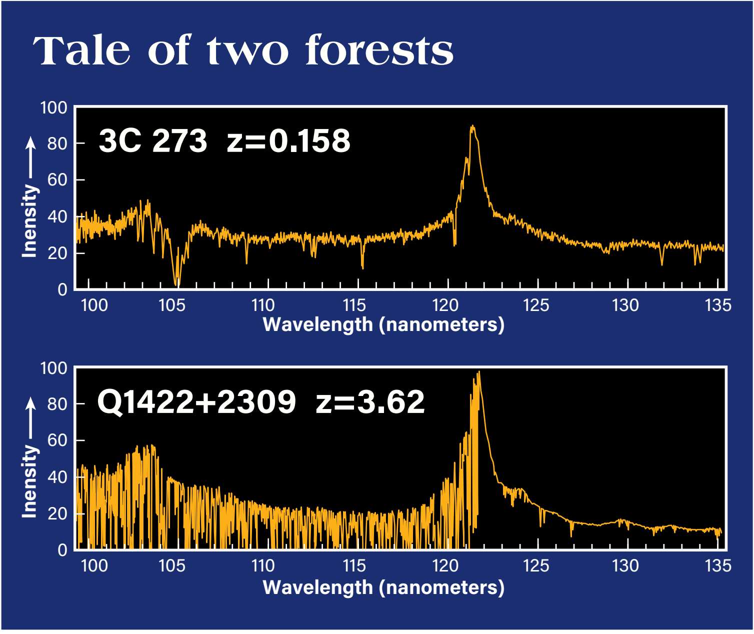

Zooming in on 3C 273

LEFT: 3C 273, the first known quasar, appears at the center of this image taken by the Hubble Space Telescope. From its bright, pointlike appearance (including diffraction spikes), it's easy to see how such objects were termed *quasi-stellar*. The quasar's jet is visible at lower right. ESA/HUBBLE & NASA

RIGHT: In 2022, an international team of radio astronomers published the deepest look yet at 3C 273's jet, effectively zooming in by a factor of around 43,000 compared to Hubble's view. The radio data were taken with the Global Millimeter VLBI Array and the Atacama Large Millimeter/submillimeter Array. HIROKI OKINO AND KAZUNORI AKIYAMA; GMVA+ALMA AND HSA IMAGES: OKINO ET AL.



By studying the Lyman-α forest in quasars both near and far, cosmologists can learn about the structure of the cosmos' web of gas clouds at various stages of the universe's evolution. That information helps improve cosmological models and narrow theories of dark matter. This image is generated by a simulation informed by Lyman-α observations and shows what the cosmic web may have looked like at a redshift (z) of 2.2, just 3 billion years after the Big Bang. NATHALIE PALANQUE-DELABROUILLE ET AL. (2015)



Tale of two forests

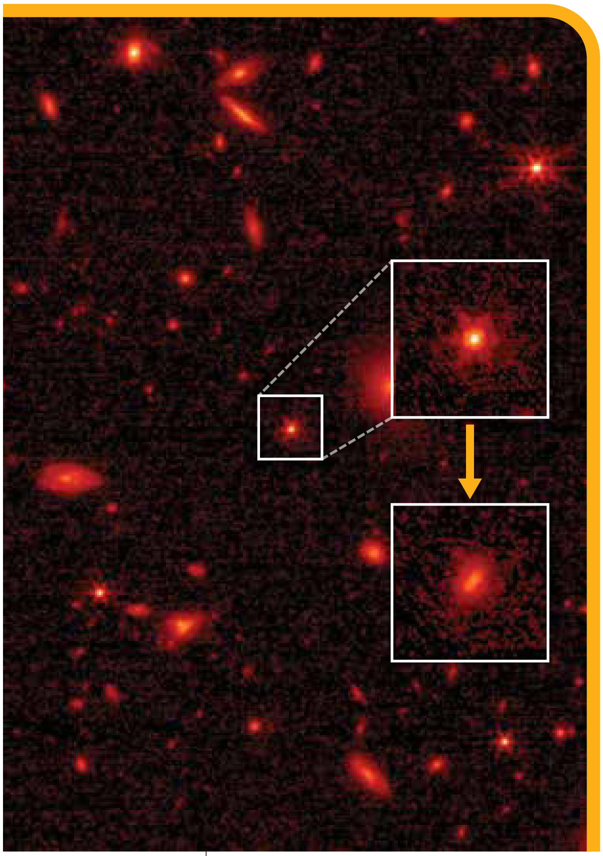
The Lyman-α forest grows with redshift, as can be seen in these two quasar spectra, which are corrected for redshift. The light from 3C 273 has traveled for roughly 2 billion years to reach us, but Q1422+2309 lies much farther; its photons have been traveling for about 12 billion years, running into many more clouds of light-absorbing gas along the way. *ASTRONOMY*: ROEN KELLY, AFTER WILLIAM KEEL. 3C 273 SPECTRUM: ROGER ANGEL/ HST/MAST. Q1422+2309 SPECTRUM COURTESY MIKE RAUCH

than 2, they noticed a new characteristic in their spectra: Just next to the quasar's Lyman-alpha (Lyman-α) emission line stood a series of narrow absorption lines, extending to shorter wavelengths. (Lyman-α emission comes from hydrogen atoms whose electron falls to the ground state from the next highest energy level; it has a wavelength in the ultraviolet of 122 nanometers.) In 1971, Roger Lynds deduced that these absorption features, dubbed the Lyman-α forest, arise from cold hydrogen gas in foreground objects that absorb the quasar's Lyman-α emission. Because these objects lie a bit closer to Earth they have smaller redshifts, so the lines appear at slightly bluer (shorter) wavelengths.

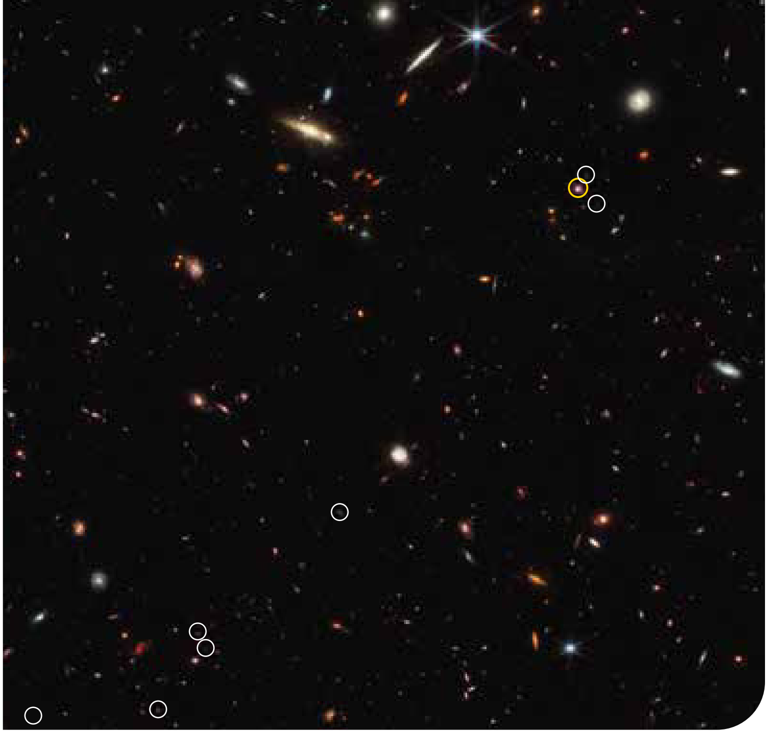
Each "tree" in the forest corresponds to a separate cloud of intergalactic hydrogen lurking in a foreground galaxy cluster. The fact that the trees grow more numerous closer to the quasar means the early universe possessed more galaxy-building material. Recently, astronomers have found similar forests attached to emission lines of heavier elements, revealing that the infant cosmos wasn't just a pristine mix of hydrogen and helium.

Pushing the limits

To extend the boundaries of our understanding to the edge of the



LEFT: JWST enables astronomers to study the host galaxies of quasars in the early universe. The quasar HSC J2236+0032 (top inset) appears as it was when the universe was just 870 million years old; subtracting the light from the quasar reveals the much fainter starlight of the surrounding galaxy (bottom inset). DING, ONOUE, SILVERMAN, ET AL.



RIGHT: The quasar J0305-3150 (circled in yellow), anchors a filament of 10 galaxies that date to just 830 million years after the Big Bang. The 3-million-light-year-long filament is imaged here by JWST. (Some circles include more than one galaxy.) IMAGE: NASA, ESA, CSA, FEIGE WANG (UNIVERSITY OF ARIZONA). IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

FROM BLACK HOLE TO GALAXY TO THE COSMIC WEB, THEY ALL ARE PART OF THE SAME COSMIC ECOSYSTEM.

observable universe, astronomers need the power of the James Webb Space Telescope (JWST). Its 6.5-meter mirror gathers more light than most ground-based telescopes, and its sensitivity to near-infrared light makes it ideal for viewing galaxies and quasars at the highest redshifts.

University of Arizona astronomer Feige Wang studies the most distant quasars and their environments, particularly those with redshifts greater than 5. Scientists so far have found about 1,000 quasars at these distances, but only 200 lie beyond redshifts of 6 and just a handful exist at redshifts of 7 or more.

Wang and his colleagues are observing 25 distant quasars with the new space telescope, using a mode that allows them to measure the redshift not only of the quasars but also all surrounding objects in the field of view.

In late June, the team announced their initial results. The first quasar in their study hosts a dark matter halo on the order of a trillion solar masses and anchors a 3-million-light-year-long filament of 10 galaxies. “This is one of the most extended and richest protoclusters yet known in the early universe,” says team member Xiaohui Fan of the University of Arizona. “It shows that luminous quasars powered by supermassive black holes (in this case about 1 billion solar masses) are at the center of an emerging large-scale structure.” Fan adds that if we could see this region as it exists today, the protocluster would likely have evolved into a rich galaxy cluster.

In a second study, the astronomers measured the sizes of the supermassive black holes in eight quasars, all of which have redshifts around 6.7, so we see them as they were some 800 million years after the Big Bang. All eight tip the scale at about a billion solar masses. “We also observed strong winds powered by the central black holes that could extend to the scale of quasar host galaxies,” says Wang. “This provides observational evidence of the existence of quasar feedback in the early universe.”

Of course, eight is a small sample size. Wang says that future JWST observations of a large number of supermassive black holes will provide statistical information about “the general properties of the earliest black holes and help us to understand the interplay between black holes and their host galaxies.”

The findings are changing how astronomers think about galaxy evolution, including the question of which came first: the galaxies or the supermassive black holes at their centers. When astronomers first uncovered the relation between galaxy and supermassive black hole masses, “it seemed crazy to think the black holes came first,” says Keel. “But seeing some quasars with billions of solar masses in the early universe, even if they weren’t first, they must have gotten a head start on growth compared to the surrounding galaxies.”

P172+18 is the most distant known quasar, appearing to us (and in this illustration) as it was when the universe was just 780 million years old. It is also one of the small fraction of quasars that are radio-loud. ESO/M. KORNMESSER

The future beckons

JWST's time may be precious, but that won't keep astronomers from using it to further explore quasars and the nascent universe.

The early results have been tantalizing, and the relationships between the major players in the cosmos' first billion years are starting to come into focus.

"The connection is that in the early universe, the most luminous quasars are powered by the most massive black holes, in the most massive galaxies, and residing at the centers of the largest structures with the most active galaxy formation," says Fan. "So, from black hole to galaxy to the cosmic web, they are all part of the same cosmic ecosystem."

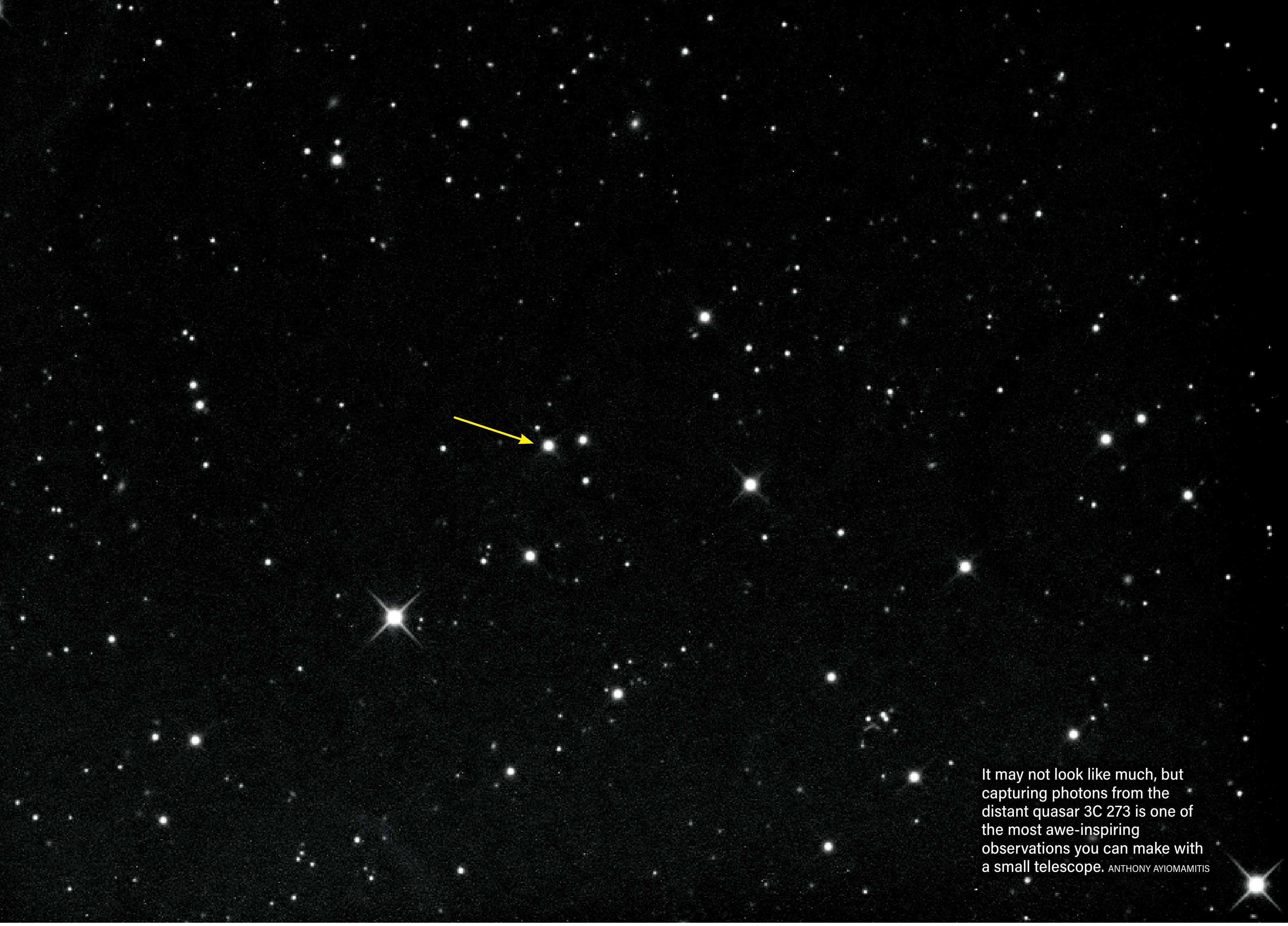
The findings seem consistent with the apparent coevolution between supermassive black holes and galaxies in the more mature universe. Perhaps the biggest mystery to solve will be finding out how such large structures managed to form so quickly after the Big Bang. (See "Too big, too soon" in the September 2023 issue.)

Fan sees a future where JWST not only investigates the roles of black hole and quasar creation in the context of galaxy formation, but also probes how quasars anchor the universe's earliest large-scale structures. Keel foresees quasars continuing their yeoman work as beacons lighting up the intergalactic medium and revealing its composition.

Whatever the future may bring, it seems certain quasars will keep astronomers busy for another 60 years.

Quasars and other cosmic enigmas have always drawn the curiosity of Contributing Editor **Richard Talcott**.

HE0435-1223 is a quasar whose light has been gravitationally lensed by a foreground galaxy, creating four images of the quasar surrounding the lens. Because the light from each image has taken a different path, it arrives at different times, and these delays are amplified by the expansion of the universe. Astronomers can use such objects as one method to measure how fast the universe is expanding. ESA/HUBBLE, NASA, SUYU ET AL.



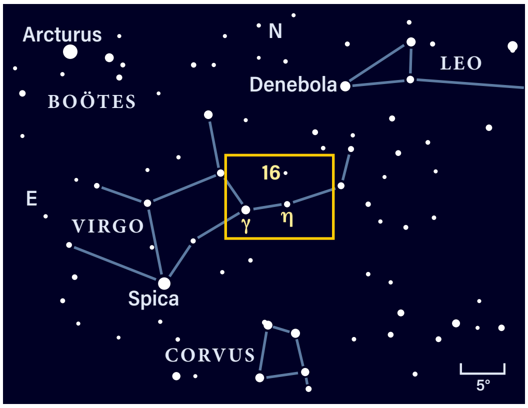
It may not look like much, but capturing photons from the distant quasar 3C 273 is one of the most awe-inspiring observations you can make with a small telescope. ANTHONY AYIOMAMITIS

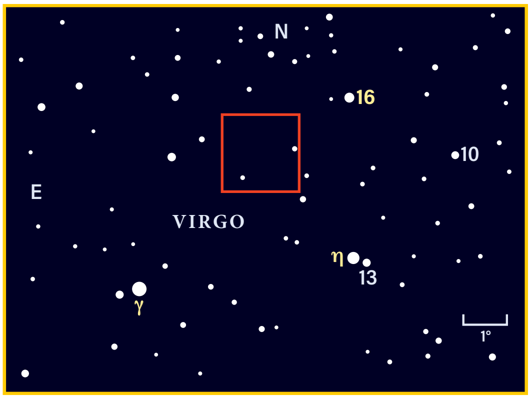
Hunting quasar 3C 273

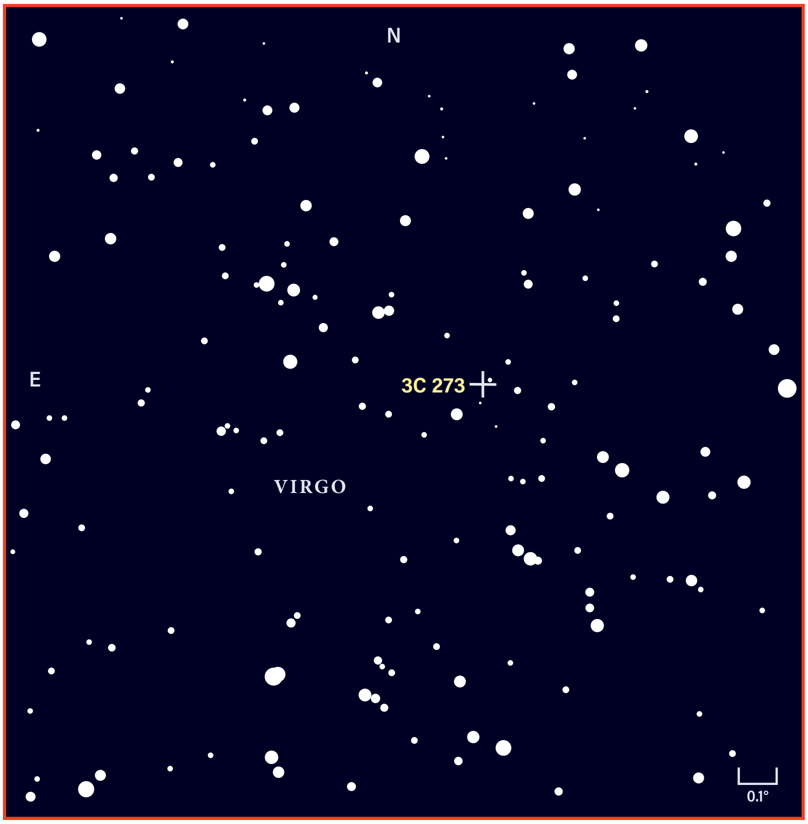
Accept the challenge of tracking down the sky's brightest quasar through your telescope. BY RICHARD TALCOTT

SOME DEEP-SKY OBSERVERS prefer viewing intricate features in emission nebulae or star clusters within the Milky Way. Others seek out faint structures in distant galaxies. Alas, the quasar 3C 273 can't compete on those terms.

What 3C 273 offers instead is the chance to see the most distant object visible through a modest telescope. The photons that travel down your scope's tube and into your eyeball left 3C 273 some 2 billion years ago, around the time complex life first appeared on Earth. Although you won't discern any detail in the quasar, the mere sight of its light should thrill even the most jaded observer.







TOP LEFT: Quasar 3C 273 lies in a fairly sparse region of western Virgo, between the Maiden's Spica and Leo the Lion's Denebola. This naked-eye view shows stars to magnitude 5.0. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

BOTTOM LEFT: This binocular chart goes down to magnitude 8.0 and homes in on the area around 5th-magnitude 16 Virginis, the gateway to 3C 273.

RIGHT: Use this telescopic map revealing stars to magnitude 13.5 to identify the quasar 3C 273 across 2.3 billion light-years of space.

Tricks of the trade

3C 273 glows at magnitude 12.9, which puts it within range of a 6-inch telescope on an especially good night. An 8-inch instrument provides more leeway, particularly if you're quasar hunting for the first time.

A few tips make the task easier.

First, choose an observing site far removed from the lights of the city. Even a nearby streetlight or a neighbor's security light can doom your effort.

Second, pick a night when the Moon is out of the sky. Our satellite's natural light pollution spoils the view just as much as civilization's artificial variety.

Third, select a night when 3C 273 rides high in the sky. Looking through thicker layers of atmosphere when an object lies closer to the horizon dims it, and you want as many photons making their way to your telescope as possible.

The quasar resides in western Virgo the Maiden, a region that lies fairly low in the east as morning twilight begins in November. A couple of months make a big difference, however. 3C 273 peaks in the south before dawn in January and at progressively earlier times as the year advances. It's up all night and highest around midnight during April.

Zeroing in on 3C 273

The final trick to identifying the quasar is knowing precisely where to look. The charts above will take you there step by step. All the maps show north at top and east to the left. This means the naked-eye and binocular fields match what you will see when 3C 273 lies due south. If your telescope reverses the image and puts south at top, turn the magazine upside down to match the view. Even if you have a go-to scope, you'll need the detailed telescopic map to identify which dot in the field is 3C 273.

The map above at top left shows a wide-field naked-eye view of the area down to magnitude 5.0. First, identify Virgo's luminary, 1st-magnitude Spica, and Leo the Lion's second-brightest star, 2nd-magnitude Denebola. Next, focus your attention roughly halfway between these stars on a trio of fainter suns: 3rd-magnitude Gamma (γ), 4th-magnitude Eta (η), and 5th-magnitude 16 Virginis. This region shows up best in the binocular field above at lower left, which reveals stars as faint as magnitude 8.0.

3C 273 lies 2.5° southeast of 16 Vir. I find it easiest to start at this 5th-magnitude sun because the stars along the way to the quasar form more conspicuous patterns. The large telescopic view above at right shows objects to magnitude 13.5, faint enough that you shouldn't have much trouble homing in on 3C 273. Look for a closely spaced trio of stars forming a right triangle. The starlike quasar lies halfway along this triangle's hypotenuse. Don't confuse it with a slightly fainter sun just to its west.

Once you've found 3C 273, take a moment to ponder what you're seeing: light that began its journey long before dinosaurs roamed Earth and ended by tickling the delicate rods and cones in your eye. ◐

Contributing Editor **Richard Talcott** *looks forward each year to another opportunity to track down 3C 273.*

ASHES TO ASHES, DUST TO PLANETS

JWST discovers three dust-filled rings around the star Fomalhaut, hinting at possible embedded planets.

BY RICHARD TALCOTT

THROUGHOUT RECORDED HISTORY, Fomalhaut's main claim to fame has been its rank as the sky's most isolated 1st-magnitude star. The luminary of Piscis Austrinus stands alone on autumn evenings, a beacon in the southern sky amidst a smattering of less impressive suns.

Then, 40 years ago, astronomers discovered excess infrared radiation pouring from the night sky's 18th-brightest star. As scientists pointed ever-more-powerful telescopes in its direction, a picture emerged of an otherwise normal sun surrounded by a disk of warm dust.

Researchers now have targeted this nearby star with their latest and greatest infrared instrument — the James Webb Space Telescope (JWST). JWST's images found not one but three nested belts of warm dust surrounding Fomalhaut, the inner two of which had never been seen before. The findings strongly suggest that planets shape the debris disk.

A DUSTY STAR

The modern story of Fomalhaut begins in 1983. That's when NASA's Infrared Astronomical Satellite conducted an all-sky survey for sources of infrared radiation. No one expected to see much coming from relatively hot stars like Fomalhaut. But there it was: a strong signal that could only mean warm dust, likely in a debris disk formed as asteroids and comets left over from the formation of planets collided and got ground into finer particles.

In the decades since, astronomers examined Fomalhaut across the electromagnetic spectrum, from optical to infrared and radio. The observations revealed a narrow ring located between 136 and 150 astronomical units from the star. (One astronomical unit, or AU, is equal to the average Earth-Sun distance of 93 million miles [150 million kilometers].)

That's where JWST comes in. With its infrared sensitivity fine-tuned to dust emission and its giant 6.5-meter mirror to resolve fine detail, the space telescope proved the perfect instrument for exposing the structure of Fomalhaut's debris disk.

FUN FACTS

Star name
Fomalhaut

Spectral type
A3V

Distance
25 light-years

Mass
1.92 solar masses

Surface temperature
8,590 kelvins (1.5 times hotter than the Sun)

Luminosity
16.63 times the Sun

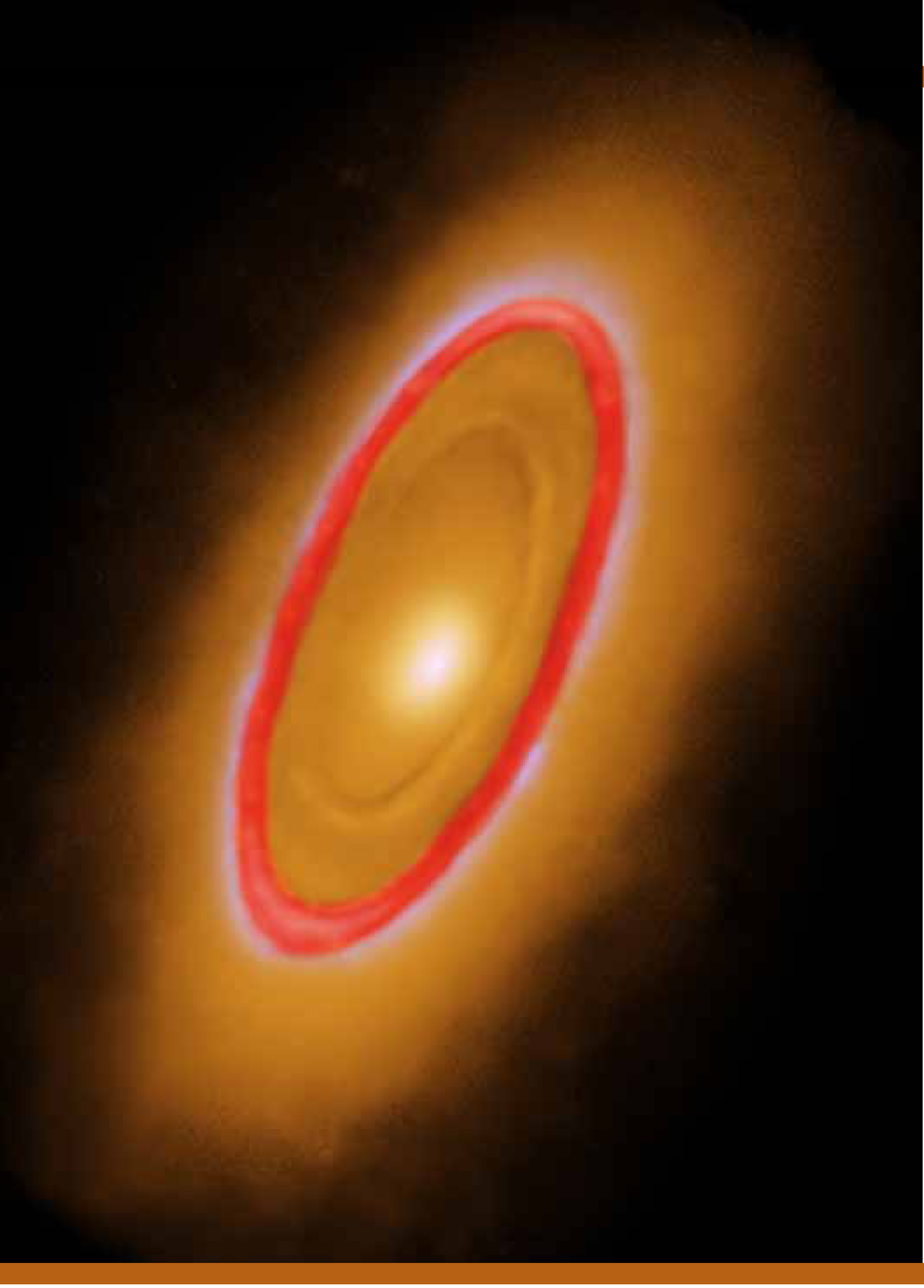
Age
440 million years

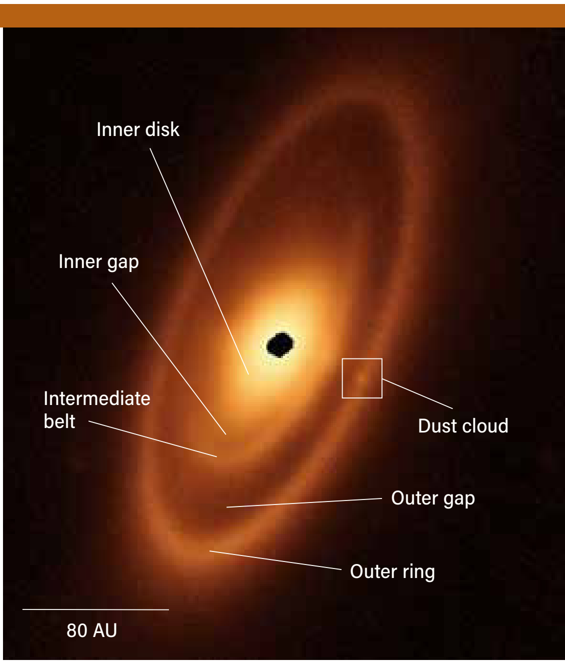
RINGS INSIDE A RING

The observations reveal that the previously seen narrow ring lies outside two smaller belts closer to the star. In many ways it mimics the structure in our own solar system. The outer ring resembles our Kuiper Belt, which starts just outside Neptune's orbit at 30 AU and extends out to 55 AU. Fomalhaut's analogue stretches nearly three times as far. Neptune sculpts the inner edge of the Kuiper Belt — could an unseen planet perform the same task at Fomalhaut? A large dust cloud resides in this ring and a faint halo lies outside it.

The interior belts are a revelation, never glimpsed before these JWST observations. The innermost disk appears somewhat similar to our asteroid belt, though again Fomalhaut's extends much farther, from about 10 to 73 AU. (The Sun's belt runs from 2.1 to 3.3 AU and Jupiter shepherds its outer edge.)

Beyond this is where it gets interesting. A noticeable gap surrounds the inner





CLOCKWISE FROM LEFT:

This composite image combines infrared data from JWST (yellow-orange) with optical observations from Hubble (light blue) and radio wavelengths observed by ALMA (dark pink). ADAM BLOCK/ANDRAS GÁSPÁR/STEWARD OBSERVATORY/UNIVERSITY OF ARIZONA

Three nested dust belts surround the star Fomalhaut in this JWST image. A coronagraph blocked the light from the star and its immediate surroundings. NASA/ESA/CSA/A. PAGAN (STSCI)/A. GÁSPÁR (UNIVERSITY OF ARIZONA)

Fomalhaut's outer dust ring shows up clearly in visible light with the power of the Hubble Space Telescope. NASA/ESA/P. KALAS AND J. GRAHAM (UNIVERSITY OF CALIFORNIA, BERKELEY)/M. CLAMPIN (NASA'S GSFC)

disk and stretches for about 10 AU. Outside this relatively unpopulated region lies an intermediate belt that runs from 83 to 104 AU. More emptiness encloses this structure until you reach the outer ring. This gap likely results from the gravitational effects of an unseen planet with a mass no greater than that of Saturn.

"The belts around Fomalhaut are kind of a mystery novel," said University of Arizona astronomer and team member George Rieke in a press release. "Where are the planets? I think it's not a very big leap to say there's probably a really interesting planetary system around the star." Team member Schuyler Wolff of the University of Arizona added, "We definitely didn't expect the more complex structure with the second intermediate belt and the broader asteroid belt."

Indeed, the Sun doesn't have a two-tiered asteroid belt. And so far, these are the only two stars studied at this level of detail, leaving astronomers to wonder which architecture might be more common. The team plans to observe two other dust-wrapped stars, Vega and Epsilon Eridani, in the near future to find out.

Contributing Editor ***Richard Talcott*** *wrote about JWST's observations of Cassiopeia A in the October issue.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

NOVEMBER 2023

Jupiter and its Galilean moons are on full display as the gas giant reaches opposition this month. Here, the mighty planet poses with its largest moons. PAUL STEWART

Jupiter climbs high

Saturn is already visible after dark while Jupiter is rising in the eastern sky, beckoning for attention all night. Uranus is at its best for the year and Neptune is also on display — more of a challenge, but with a helpful star nearby. Venus continues its brilliant predawn showing all month and can't be missed, rising about four hours before the Sun.

Our planetary observing begins with the reappearance of **Mercury** in the evening sky. It's a challenge due to its southerly declination, although lucky observers might spot it 5° to the right of a 38-hour-old crescent Moon Nov. 14 (you'll need a clear southwestern horizon). Both stand 3° above the horizon 20 minutes after sunset and set quickly — you have about 10 minutes to spot them. Mercury glows at magnitude –0.5.

There's gentle improvement as Mercury's elongation from the Sun increases daily, reaching 20° east of our star on the 27th, when it sets an hour after the Sun. As November ends, Mercury stands 5° high in the southwest 30 minutes after sunset.

Saturn lies in the south as the sky darkens. Starting the month at magnitude 0.7 and standing 35° high for U.S. observers at midlatitudes, it outshines Fomalhaut, a bright star slightly east of the planet and halfway between it and the horizon. Saturn dims slightly to magnitude 0.8 in the third week of the month.

Saturn stops moving retrograde on the 4th and resumes an easterly trek across southern Aquarius. Its motion away from Iota (ι) Aquarii is barely noticeable until late November. The nearly First Quarter Moon stands within 10° of the planet on the 19th.

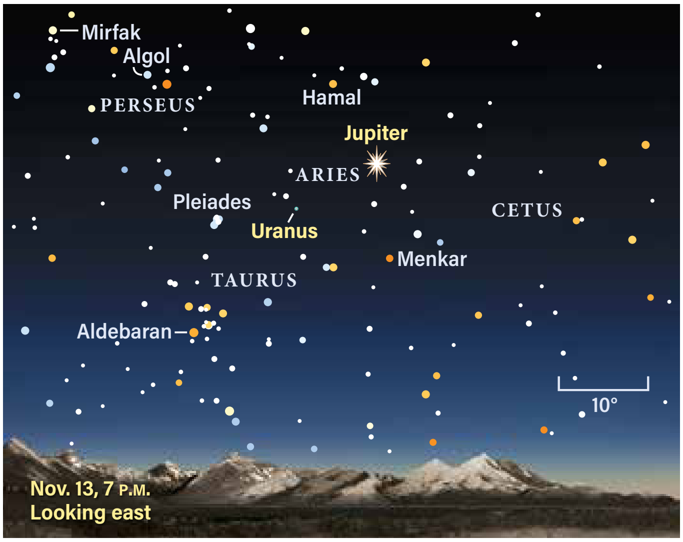
Saturn sets shortly before 2 A.M. local daylight time on the 1st and just before 11 P.M. local time on the 30th. Any telescope will reveal the rings. They span almost 40" at their widest; the narrow axis is 6". Brightest is Ring B, bounded by the dark Cassini Division and dimmer outer A Ring. The innermost C Ring is partly transparent.

The narrowing tilt of the rings over the past few years is revealing the planet's southern hemisphere. Be on the watch for new features in Saturn's normally hazy atmosphere. Subtle belts and zones are visible under steady seeing conditions.

Of Saturn's moons visible in a small backyard scope, Titan is brightest. You'll pick it up at magnitude 8.6, orbiting every 16 days. Find it roughly north of the planet Nov. 10 and 26, and roughly south Nov. 2 and 18.

Tethys, Dione, and Rhea are the next easily spotted moons at 10th magnitude. They lie inside Titan's orbit and are joined by fainter Enceladus and Iapetus, all on the western side of the rings, on Nov. 7. Eleventh-magnitude Iapetus is at inferior conjunction and unusually close to the planet. It lies between Rhea and Dione. Magnitude 12 Enceladus is challenging in smaller scopes due to Saturn's brilliance. It lies south of Dione in the early evening. Between 9 P.M. and 10 P.M. EST, these five moons curve around the western end of the rings. Watch this collection over an hour to see their relative motions upset the nice, smooth arc.

Two giants



Uranus reaches opposition 10 days after Jupiter. The ice giant lies between Jupiter and the Pleiades. Can you see it without binoculars? ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

JUPITER reaches opposition Nov. 3, followed by **URANUS** reaching opposition Nov. 13.

Tethys undergoes transits two nights apart, on Nov. 18 and 20. Both times it is followed by its shadow. It's best to record such events with a high-speed video camera designed for planetary observation.

Tethys' transit on the 18th begins around 11:35 P.M. EST and lasts nearly 80 minutes. On the 20th, the transit begins around 8:50 P.M. EST and lasts about the same duration. Plan to be observing 15 to 20 minutes before the start.

After inferior conjunction, Iapetus moves toward its brighter western elongation, which it reaches Nov. 27. At this location in its orbit, the moon is nearly 10th magnitude and stands 8.5' west of the planet.

Neptune is visible much of the night in Pisces. Binoculars or a small scope will show the magnitude 7.7 planet, which lies more than 29 astronomical units (2.7 billion miles; 1 astronomical unit [AU] is the average Earth-Sun distance) from Earth. It sits 5° due south of 4th-magnitude Lambda (λ) Piscium. 20 Psc lies about 1.5° east-northeast of the planet, shining at 5th magnitude.

Neptune's retrograde motion carries it back into northeastern Aquarius by the end of the month. A telescope will show the bluish, 2"-wide disk.

Jupiter is visible all night and reaches opposition Nov. 3. This is the best time

— *Continued on page 34*

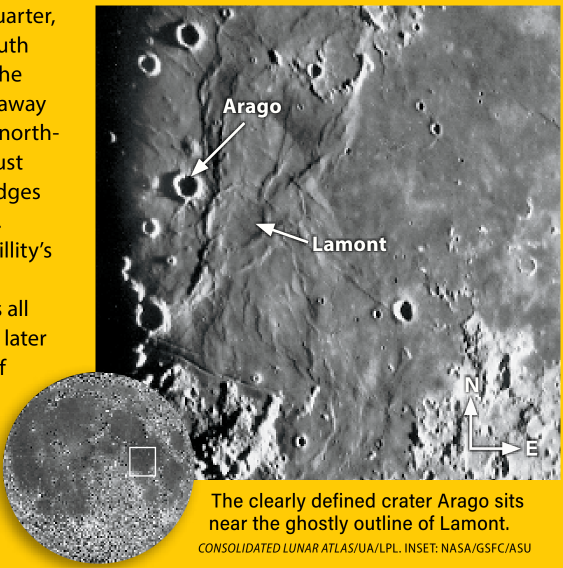
RISING MOON | The ghost ring

THE WAXING CRESCENT MOON is a crowd pleaser and a selenophile's delight. On the evening of the 18th, two nights before First Quarter, the bewildering spread of craters in the south gives way to the wrinkled ridges crossing the darker lava seas to the north. Pry your eye away from the fantastic Serpentine Ridge in the northern half of the Moon and settle on a spot just above the equator, where a wild zone of ridges plies the frozen face of Mare Tranquillitatis.

Literally buried under the Sea of Tranquillity's mostly north-south ridges is a ghostly ring named Lamont. Astronomers believe this is all that's left of a modestly large impact basin, later flooded to the rim by the upwelling lavas of eons ago. Afterward, a smaller impactor carved out the crater Arago to the northwest. A second concentric ring, about twice the size of Lamont, is trickier to see and seems easier when you're not trying hard. Multiple rings are a common feature of the larger basins. Just north of Arago is a modest bump, the largest of a family of volcanic domes in the neighborhood.

Both the wrinkles and domes are so gentle that without the low Sun angle they will disappear by the 19th. Should the 18th be cloudy, take your next opportunity and instead drift on any lunar sea near the terminator. Wrinkles, bumps, and cracks await!

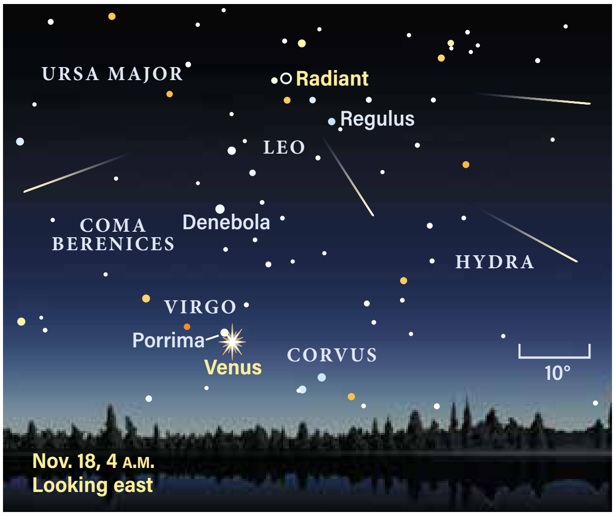
Arago and Lamont



The clearly defined crater Arago sits near the ghostly outline of Lamont.
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Look to the Lion

Leonid meteor shower



The Leonids' radiant will rise to higher than 60° elevation in the south by dawn.

THIS YEAR'S ANNUAL LEONID meteor shower peaks Nov. 17/18 during nighttime across the U.S. It coincides with a five-day old crescent Moon that sets before 10 P.M. local time. The Leonids are associated with Comet 55P/Tempel-Tuttle, which last reached perihelion in 1998.

In recent years, hourly rates have been declining and are not expected to improve for a few years. However, with so much planetary action going on (Jupiter is visible all night and Venus rises early), it's a great time to add in a period of meteor observing.

Leo rises around local midnight and the radiant, located in the Sickle asterism, is visible through dawn. The hour before twilight is the best time for all meteor showers, placing us on the leading hemisphere of Earth as it flies into the stream of meteor debris. The Leonids are known to be very swift, and many meteors leave glowing, persistent trains, which are fascinating to experience. Look 40° to 60° away from Leo to spot the longest trails.

The shower is active from Nov. 6 to 30, so be on watch for Leonids for at least a week or two on either side of the peak date.

LEONID METEORS

Active dates: Nov. 6–30
Peak: Nov. 17/18
Moon at peak: Waxing crescent
Maximum rate at peak:
10 meteors/hour

STAR DOME

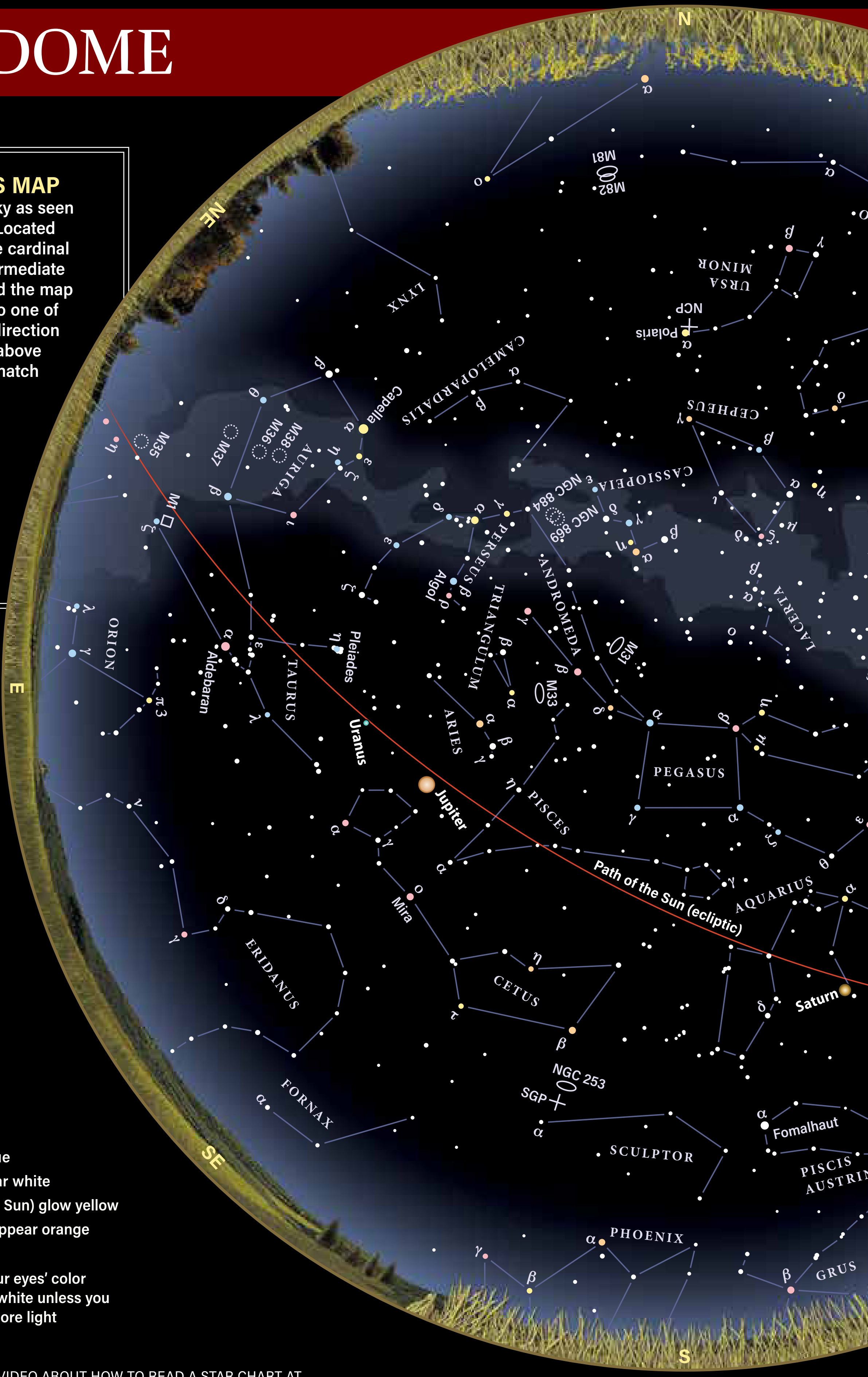
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. November 1
8 P.M. November 15
7 P.M. November 30

Planets are shown at midmonth



MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
□ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

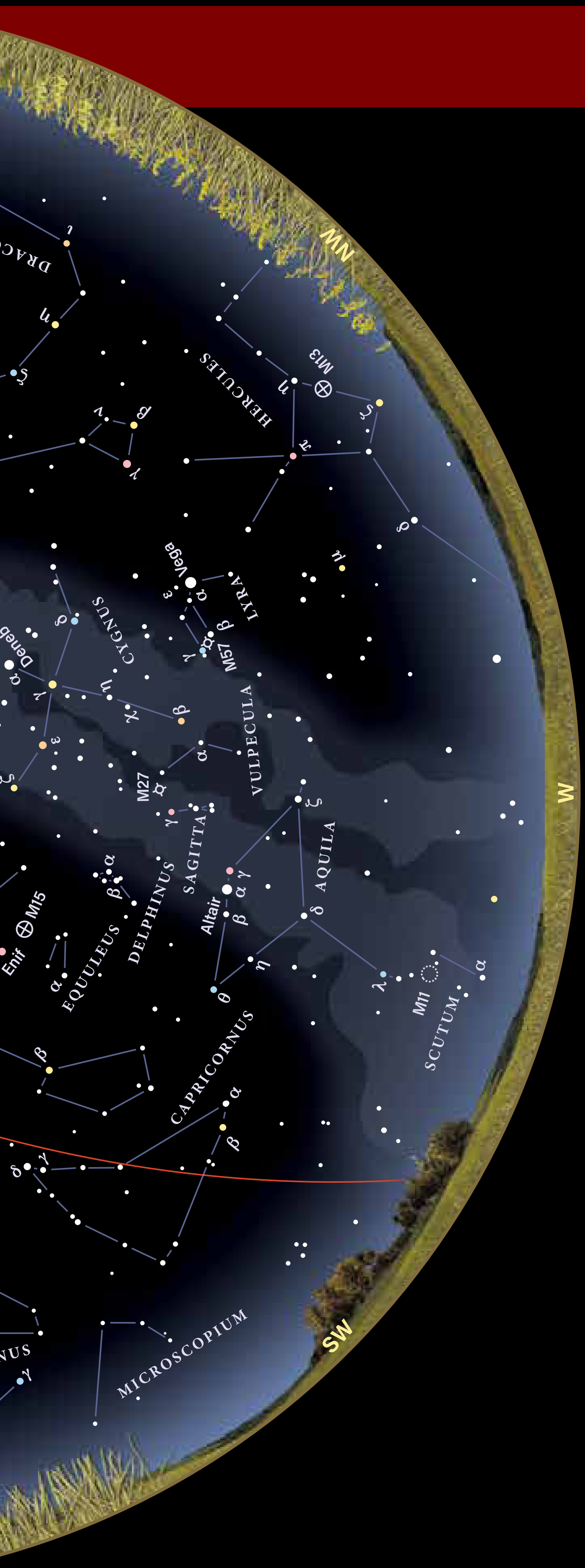
● Sirius
● 0.0 · 3.0
● 1.0 · 4.0
● 2.0 · 5.0

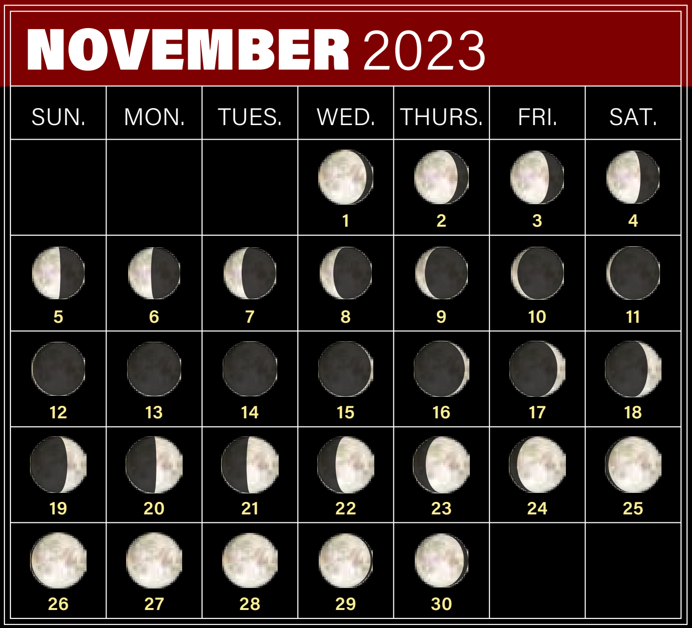
STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT
www.Astronomy.com/starchart.





NOVEMBER 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 Asteroid Vesta is stationary, midnight EDT

3 Jupiter is at opposition, 1 A.M. EDT

4 Saturn is stationary, 1 P.M. EDT

5 Last Quarter Moon occurs at 3:37 A.M. EST

Asteroid Melpomene is at opposition, 10 P.M. EST

6 The Moon is at apogee (251,388 miles from Earth), 4:49 P.M. EST

9 The Moon passes 1.0° north of Venus, 4 A.M. EST

13 New Moon occurs at 4:27 A.M. EST

Uranus is at opposition, noon EST

14 The Moon passes 0.9° north of Antares, 3 P.M. EST

16 Mercury passes 3° north of Antares, 1 P.M. EST

17 Leonid meteor shower peaks

18 Mars is in conjunction with the Sun, 1 A.M. EST

20 First Quarter Moon occurs at 5:50 A.M. EST

The Moon passes 3° south of Saturn, 9 A.M. EST

Dwarf planet Ceres is in conjunction with the Sun, 11 A.M. EST

21 The Moon is at perigee (229,795 miles from Earth), 4:01 P.M. EST

22 The Moon passes 1.5° south of Neptune, 3 A.M. EST

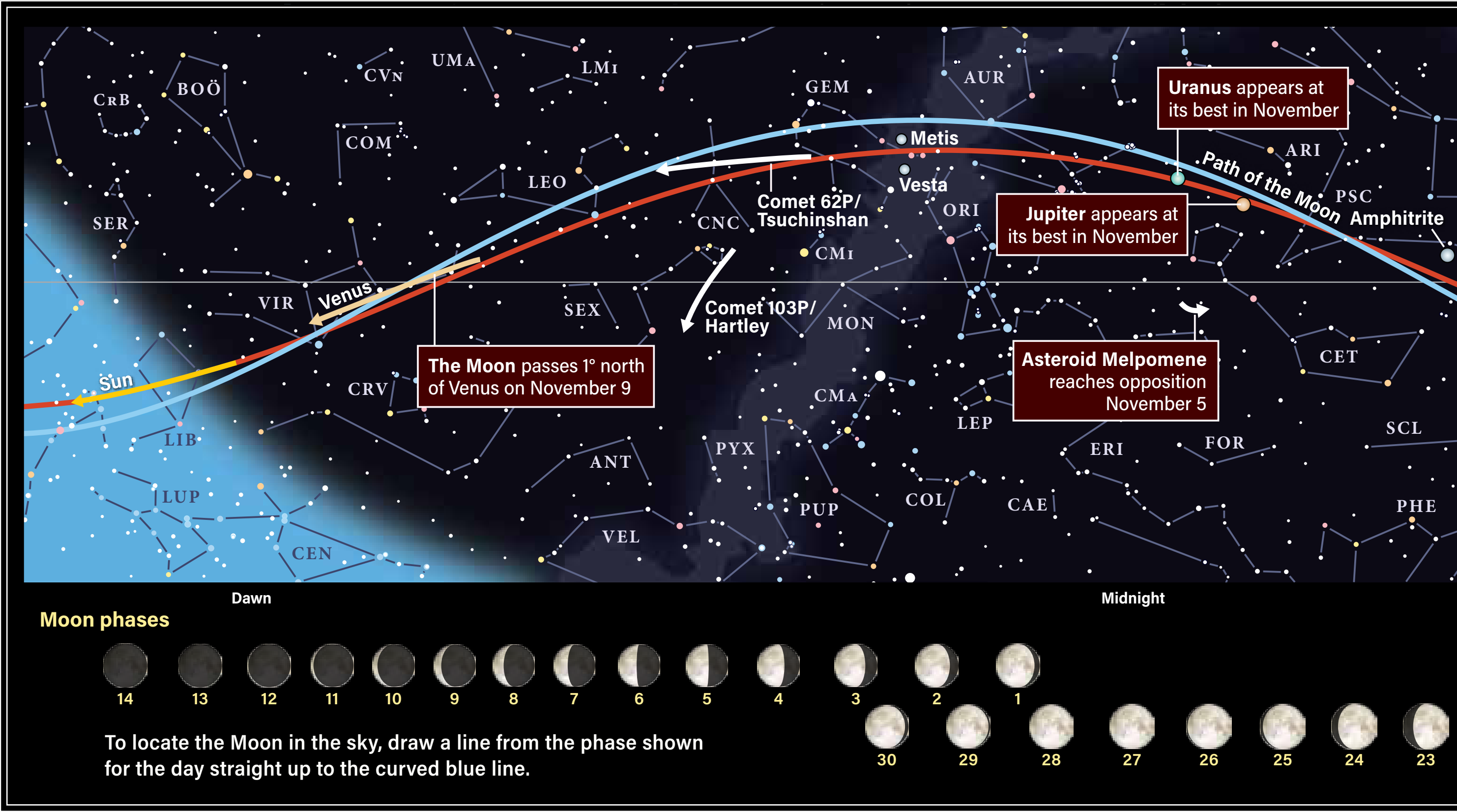
25 The Moon passes 3° north of Jupiter, 6 A.M. EST

26 The Moon passes 3° north of Uranus, 4 A.M. EST

27 Full Moon occurs at 4:16 A.M. EST

28 Venus passes 4° north of Spica, 4 A.M. EST

PATHS OF THE PLANETS



Uranus appears at its best in November

Comet 62P/Tsuchinshan

Jupiter appears at its best in November

Comet 103P/Hartley

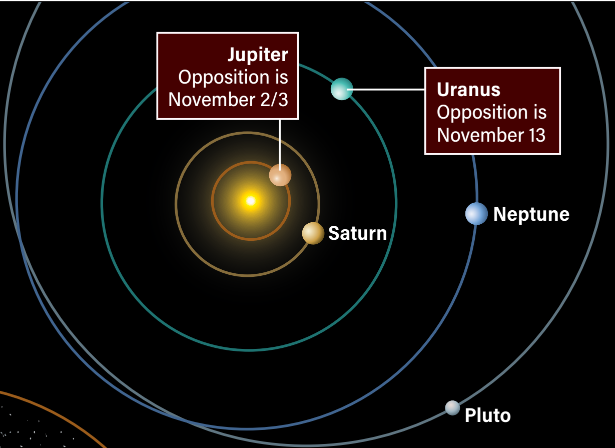
The Moon passes 1° north of Venus on November 9

Asteroid Melpomene reaches opposition November 5

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

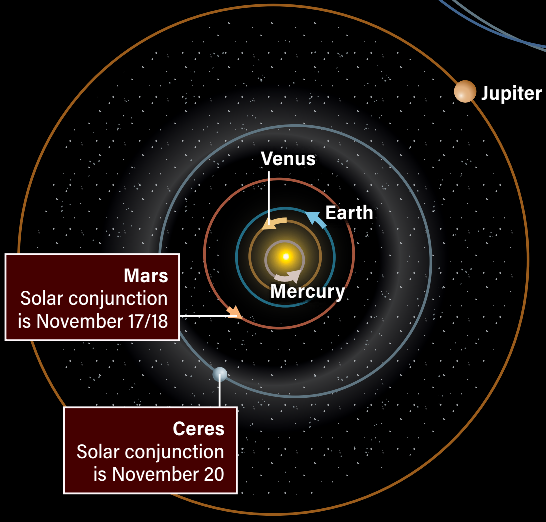
THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



Jupiter Opposition is November 2/3

Uranus Opposition is November 13

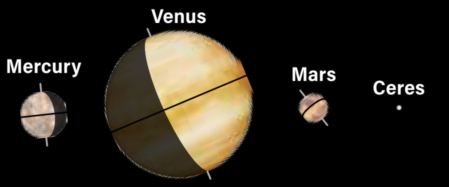


Mars Solar conjunction is November 17/18

Ceres Solar conjunction is November 20

THE PLANETS IN THE SKY

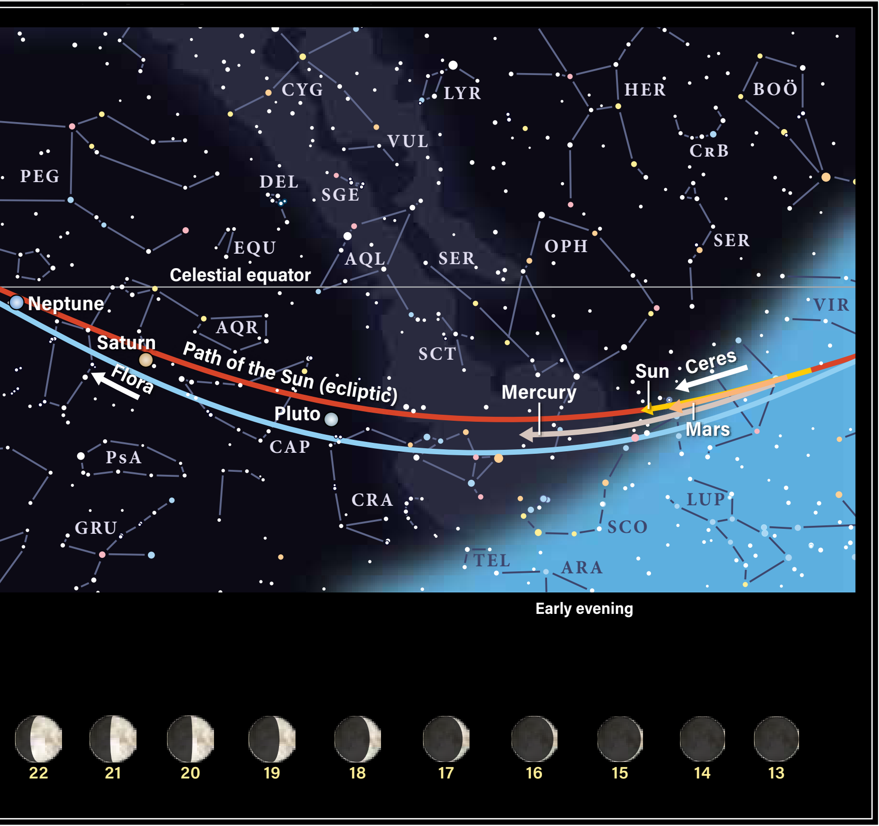
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Nov. 30	Nov. 15
Magnitude	–0.4	–4.3
Angular size	6.1"	19.4"
Illumination	74%	61%
Distance (AU) from Earth	1.111	0.859
Distance (AU) from Sun	0.396	0.719
Right ascension (2000.0)	17h49.9m	12h28.0m
Declination (2000.0)	–25°52'	–1°20'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

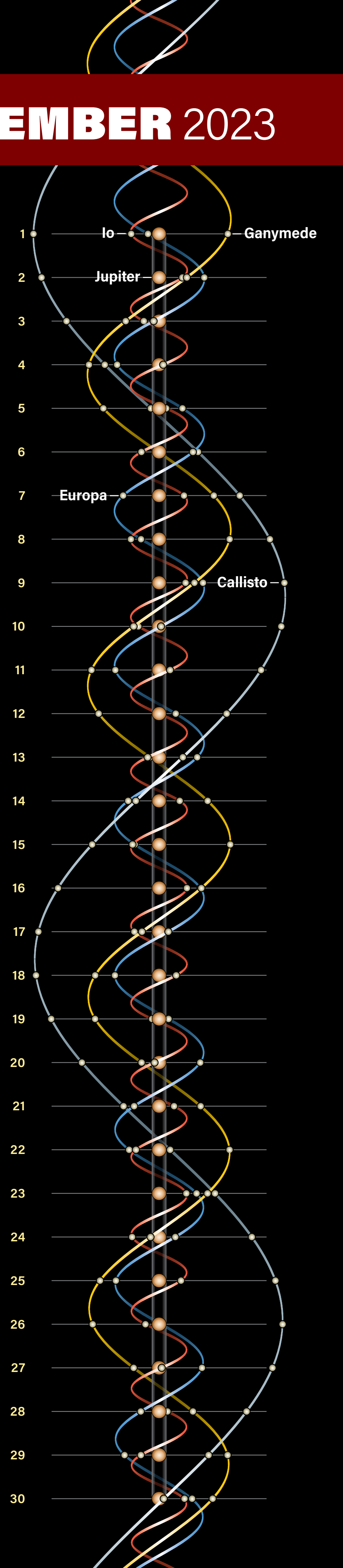
NOVEMBER 2023



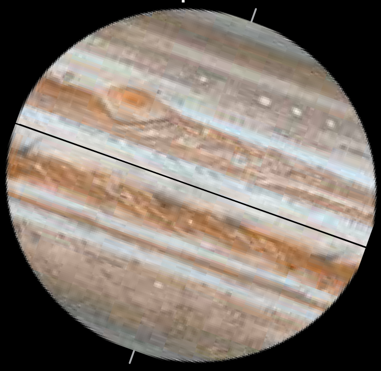
Early evening

JUPITER'S MOONS

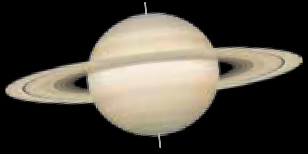
Dots display positions of Galilean satellites at 11 P.M. EST on the date shown. South is at the top to match the view through a telescope.

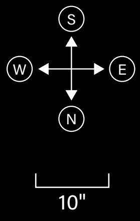


Jupiter



Saturn

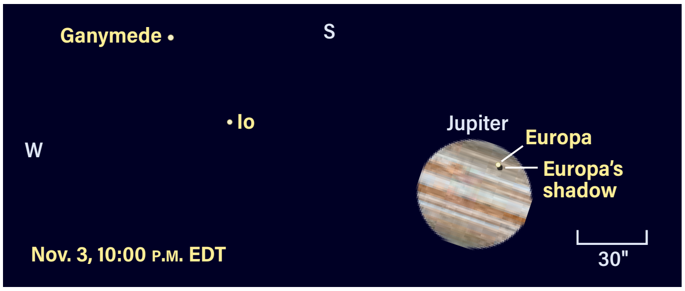




MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Nov. 15	Nov. 15	Nov. 15	Nov. 15	Nov. 15	Nov. 15	Nov. 15
1.4	8.6	–2.9	0.7	5.7	7.7	15.2
3.7"	0.4"	49.2"	17.4"	3.8"	2.3"	0.1"
100%	100%	100%	100%	100%	100%	100%
2.531	3.707	4.009	9.560	18.632	29.360	35.284
1.542	2.722	4.976	9.751	19.621	29.905	34.891
15h22.3m	15h35.0m	2h26.7m	22h11.9m	3h13.3m	23h42.5m	20h02.1m
–18°36'	–16°01'	13°03'	–12°58'	17°37'	–3°16'	–23°16'

— Continued from page 29

Close follower



At opposition, the moons and their shadows cross Jupiter at nearly the same time. Callisto lies to the west, outside this field of view.

of the year to observe the gas giant, now closest to Earth at 3.98 AU (370 million miles). It brightens the constellation Aries with its magnitude –2.9 glow. The planet's apparent diameter reaches 49" and shaves off barely an arcsecond during the rest of the month.

This large apparent size is a great benefit, particularly for observers using high-speed video. Jupiter is bright, shortening exposure times and allowing capture at a higher frame rate with good signal to noise. Shorter exposure times aid with freezing the blurring effects of our atmosphere in a bid to capture fine detail in Jupiter's atmosphere.

Jupiter also climbs higher in the sky for northern observers than at any time since 2015. The higher elevation reduces the amount of Earth's atmosphere that the planet's light passes through. Add in the long nights of early winter and an entire rotation of Jupiter can be captured in less than 10 hours.

A telescope reveals the dark equatorial belts straddling the equator. The Great Red Spot makes regular appearances, visible for some time each night. Finer and more subtle details in the ever-changing cloud belts become noticeable with patient and prolonged viewing, as your eye becomes accustomed to the planet's brilliance.

The Galilean moons also subtend a larger apparent diameter at opposition, aiding the recording of surface features with perfectly collimated telescopes and video capture. At opposition, transiting moons and their shadows nearly overlap, while later in the month you can see the same moon transiting with its shadow following later.

For example, three Io transits are visible on the evenings of Nov. 4/5, 11/12, and 20. Io and its shadow begin transiting within two minutes of each other on the 4th, starting at 11:55 P.M. EDT (note that daylight saving time ends at 2 A.M. on Nov. 5). On the 12th, Io's transit begins at 12:38 A.M. EST (late on the 11th in all other time zones) and now the shadow lags by 14 minutes, appearing at 12:52 A.M. EST. On the 20th, Io begins a transit at 8:49 P.M. EST and the shadow follows 28 minutes later, at 9:17 P.M. EST.

Europa's transits exhibit the same changing geometry. On Nov. 3, the night of opposition, the moon and shadow overlap. Europa's transit begins at 9:15 P.M. EDT and its shadow appears one minute later.

By Nov. 10, Earth is about 7° farther along its orbit, and Europa and its shadow are well separated. Europa begins its

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (southwest)
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (southeast)

MIDNIGHT
Jupiter (southwest)
Saturn (southwest)
Uranus (south)
Neptune (west)

MORNING SKY
Venus (southeast)
Jupiter (west)
Uranus (west)

COMET SEARCH | Catch the bees asleep

WE'RE TREATED for a whole week to Comet 62P/Tsuchinshan (also called Tsuchinshan 1) posing with M44 while the Moon is out of the sky. The only catch is that it's not for evening or suburban observers. Plan to be outside the city, stay up past 1 A.M., and bring along at least a 4-inch scope to spy the 10th-magnitude fuzz.

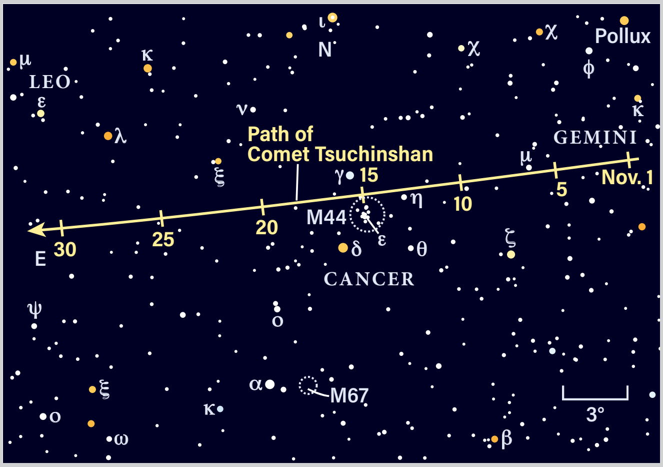
There's more to keep an eye out for: swift Leonids, fireball Taurids, and another half-dozen minor meteor showers. And by 2 A.M., the slightly brighter Comet 103P/Hartley climbs up just below Hydra's head.

Imagers can expect to capture the classic green glow surrounding Tsuchinshan 1's coma, since the comet is inside the orbit of Mars and close enough to the Sun. Consider using a 135mm telephoto lens to frame it along with the sparkly and colorful Beehive Cluster. Visually, the comet will remain gray, but what will the condensation be like? Diffuse with a bright core, or gradually brightening from the outside into the middle, reminiscent of many elliptical galaxies?

Don't expect to see or image a tail this month, except for the slightest hint. Tsuchinshan 1 is traveling just off the ecliptic and close to opposition, so the physical tails are streaming behind it in the solar wind. Perihelion, its closest approach to the Sun, occurs Dec. 25, but outside Earth's orbit.

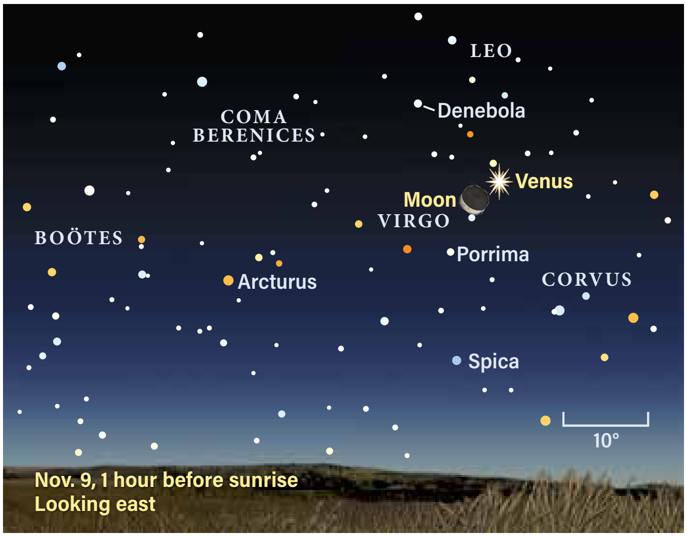
Should the name Tsuchinshan sound familiar, this observatory co-discovered C/2023 A3 (Tsuchinshan–Atlas), which will catch media attention next October, perhaps cracking magnitude 0!

Comet 62P/Tsuchinshan



Comet Tsuchinshan slides past the Beehive Cluster (M44) midmonth, offering an excellent scene for astrophotographers to capture.

Mingling in the Maiden



Nov. 9, 1 hour before sunrise
Looking east

A delicate crescent Moon shares the constellation Virgo with bright Venus for several hours before dawn on Nov. 9.

transit at 10:29 P.M. EST, followed by the shadow 22 minutes later.

Ganymede undergoes a fascinating eclipse behind Jupiter's northern limb beginning Nov. 6 at 10:44 P.M. EST. Due to the shallow angle of the limb, Ganymede will blend with Jupiter a few minutes earlier. While Ganymede ends the occultation just before 12 A.M. EST on the 7th (still firmly the 6th in other time zones), it's in Jupiter's shadow. The moon finally reappears around 12:26 A.M. EST, taking more than 10 minutes to fully emerge.

Ganymede undergoes a similar event Nov. 13/14, starting at 1:56 A.M. EST on the 14th (the 13th for the western U.S.), with shadow egress at 4:36 A.M. EST. Another interesting event occurs early on Nov. 21, best observed from the western half of the U.S. Ganymede disappears around 4:10 A.M. CST and reappears at 5:30 A.M. CST, when Jupiter is near the horizon in the Midwest. However, Ganymede remains visible only 24 minutes before entering Jupiter's extended shadow in an eclipse that lasts nearly two hours, emerging at 5:37 A.M. PST, when Jupiter is extremely low on the West Coast.

Uranus reaches opposition Nov. 13, the second major planet to do so this month. It stands roughly midway between Jupiter and the Pleiades (M45). Scan the region with binoculars to find a small group of stars glowing between 4th and 6th magnitude. The brightest star in this region, 9.5° southwest of M45, is magnitude 4.3 Delta (δ) Arietis. Uranus sits roughly 2.2° south of this star all month. A nearly Full Moon lies in the same vicinity overnight on Nov. 24/25.

Uranus glows at magnitude 5.7, an easy binocular object. An interesting test of sky conditions is to see whether you can spot the planet with the unaided eye. You'll need very dark skies away from any city lights.

During the month, Uranus moves about 1.2° westward along a retrograde path. At opposition it lies 18.6 AU (1.7 billion miles) from Earth and through a telescope reveals a tiny 4"-wide disk.

Venus is a brilliant morning star, rising 4 hours before the Sun and shining briefly at magnitude –4.4. It crosses from Leo into Virgo on the 3rd. The planet's motion carries it from near Beta (β) Virginis on the 5th and 6th to a point 1.2° south of Porrima on the 18th. A crescent Moon hangs near Venus on the morning of Nov. 9.

Venus stands 5° north of Spica, Virgo's 1st-magnitude star, on the 27th, and ends the month 4.3° northeast of this star. Following Venus through a telescope reveals its changing phase, from a slightly gibbous, 55-percent-lit disk on Nov. 1 to 67 percent lit by the 30th. At the same time, the disk shrinks from 22" to 17" across as it recedes from Earth.

Mars is too close to the Sun for observing this month and is in conjunction with the Sun on Nov. 18.

***Martin Ratcliffe** is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

LOCATING ASTEROIDS

Zeus points the way

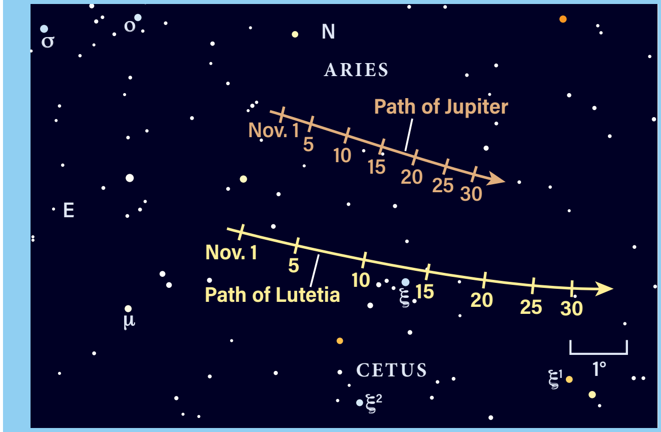
WHEN DOES AN ASTEROID'S bright signpost move? When it's a planet! All month, minor planet 21 Lutetia parallels the gas giant Jupiter's movement, almost exactly 2° to the planet's south.

Both come to opposition on the 3rd, lying opposite the Sun, when they'll be highest in the sky just after midnight for most readers. Because Lutetia orbits in the main belt between Jupiter and Mars, it is closer to us and moves faster across the sky.

The Rosetta spacecraft visited the out-of-round, 60-mile-wide asteroid in 2010. With an albedo (reflectivity) of 20 percent, Lutetia is just brighter than 10th magnitude, which means you'll need to be patient when tracking it down.

Drop down from Jupiter and match the pattern in the background stars to the view through your eyepiece, remembering that it might be upside down or flipped left to right. Make a quick sketch of the five brightest stars in the field, then come back a night or two later to see which dot moved. Just avoid the 24th through the 26th, when the Moon passes by.

Moving in sync



Asteroid Lutetia mirrors the movement of the planet Jupiter all month, albeit across a slightly longer arc.

Experience MARS in 3D

Mars is a dynamic world that continues to intrigue us. This image, captured by the Hubble Space Telescope, shows the planet wreathed in late-afternoon clouds. NASA & ALLEXXANDAR/DREAMSTIME

These stereoscopic images will transport you to the surface of the Red Planet.

BY MARY FRIARGIU

HUMANS HAVE LONG dreamt of flying to other worlds. Two destinations — the Moon and Mars — have consistently topped the wish list. Although we reached the Moon in the second half of the 20th century, Mars has remained untouched by human boots.

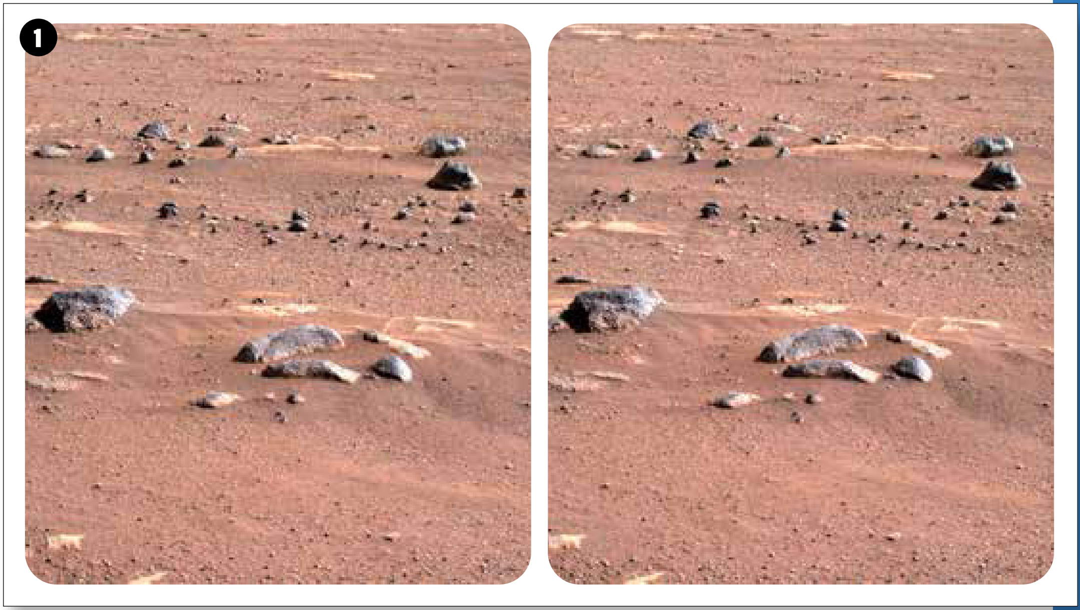
But in the late 20th and early 21st century, NASA rovers and probes have remotely explored the martian soil in our stead. Thanks to Spirit, Opportunity, Curiosity, and Perseverance, which have spent the last 20 years documenting the Red Planet in great detail, we now have quite an intimate picture of Mars.

NASA's newest Mars explorer, the Perseverance rover, launched along with its small companion, the Ingenuity helicopter, on July 30, 2020, and landed on Mars Feb. 18, 2021. The pair made this journey while the inhabitants of Earth were in the midst of the COVID-19 pandemic. In this difficult time, when people were forced to stay apart, both astrophiles and the general public joined together to celebrate the landing of this extraordinary craft.

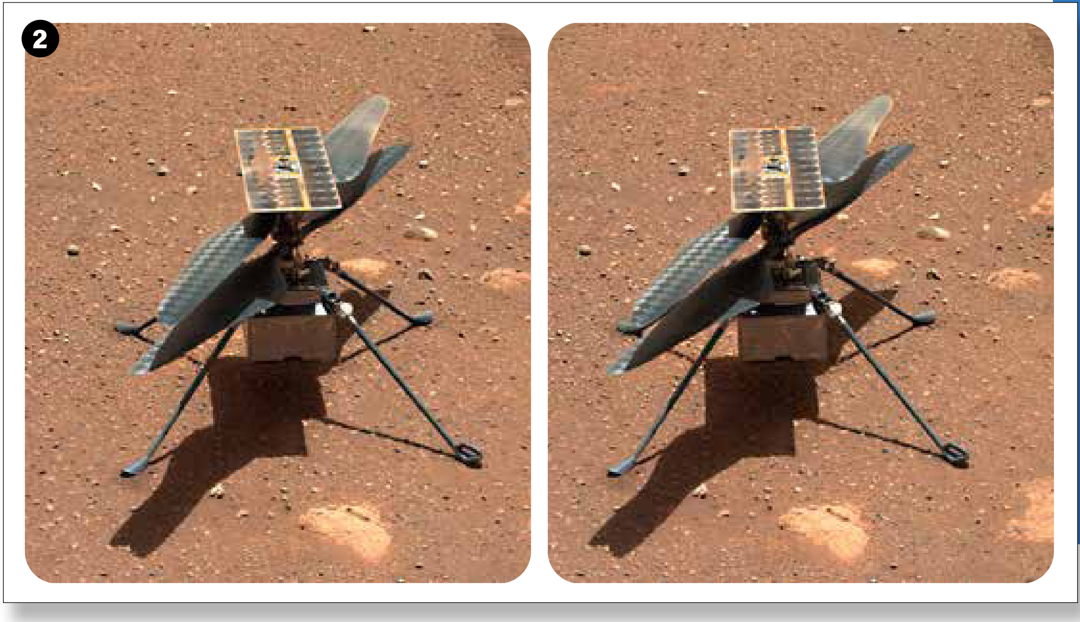
The new mission promised to communicate new discoveries from Mars as well as send back a wealth of photographic material — including stereoscopic images.

SEEING IN 3D

Perseverance has a built-in pair of zoomable stereoscopic cameras, known as Mastcam-Z, on its mast. These provide high-resolution color images of the terrain and landscape of Mars. Alongside them sits another pair of cameras designed by the engineering team at NASA's Jet Propulsion Laboratory to help navigate the rover from Earth.



1. THIS STEREO IMAGE was captured Feb. 21, 2021, during one of the first sols of the mission. Perseverance landed in the 28-mile-wide (45 km) Jezero Crater, which scientists suspect is an ancient lake and river delta — a perfect spot to start looking for traces of past life on Mars. ALL IMAGES NASA/JPL-CALTECH/ASU, STEREOS ASSEMBLED BY MARY FRIARGIU AND COLOR-PROCESSED BY BRIAN MAY UNLESS OTHERWISE NOTED



2. THE INGENUITY HELICOPTER is the first aircraft to achieve powered, controlled flight on another world. This stereoscopic portrait offers the first detailed photographic look from before its inaugural flight April 19, 2021, when Ingenuity took off, climbed to about 10 feet (3 m) above the ground, hovered in the air briefly, completed a turn, and then landed.

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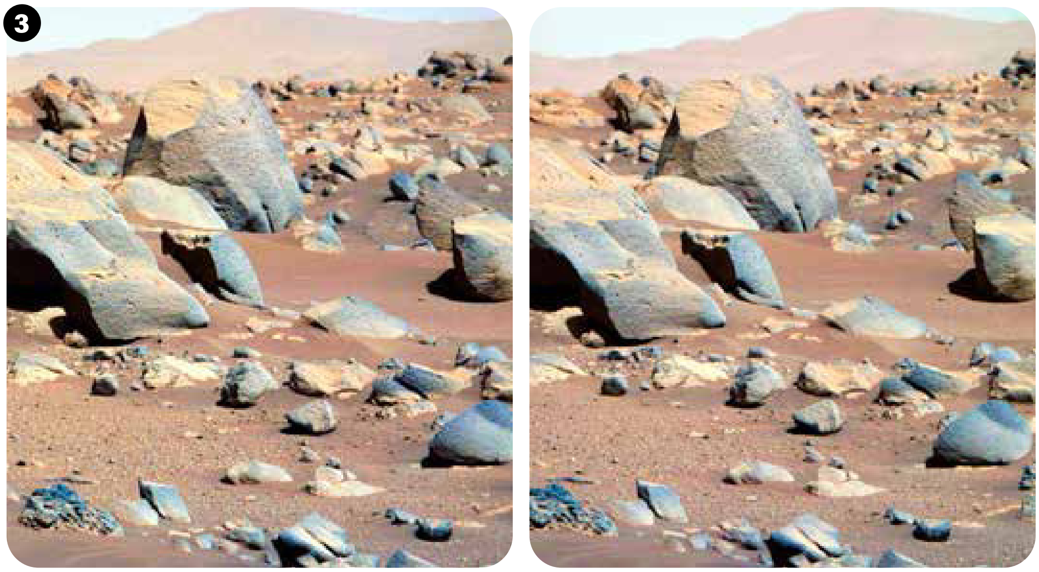

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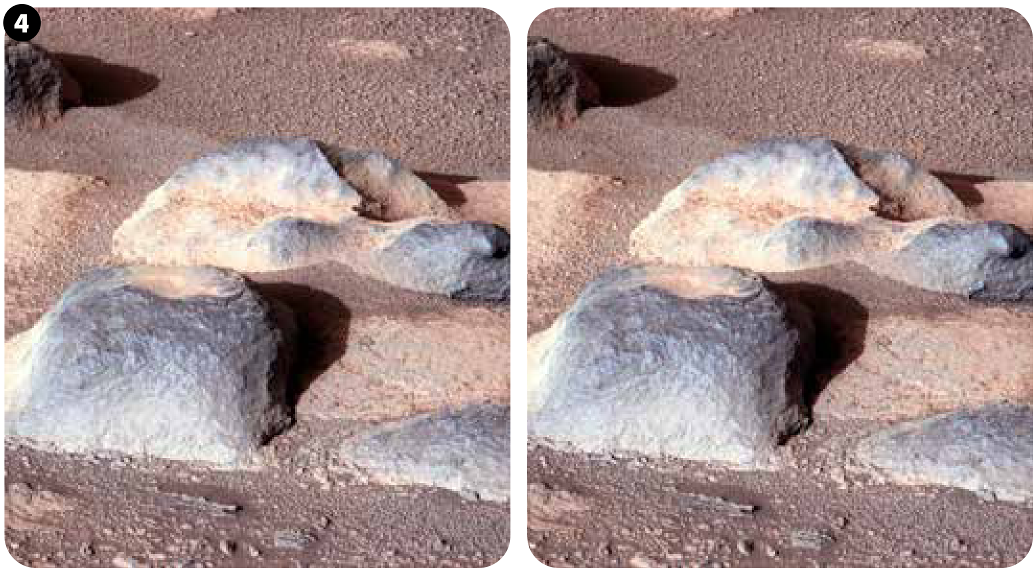

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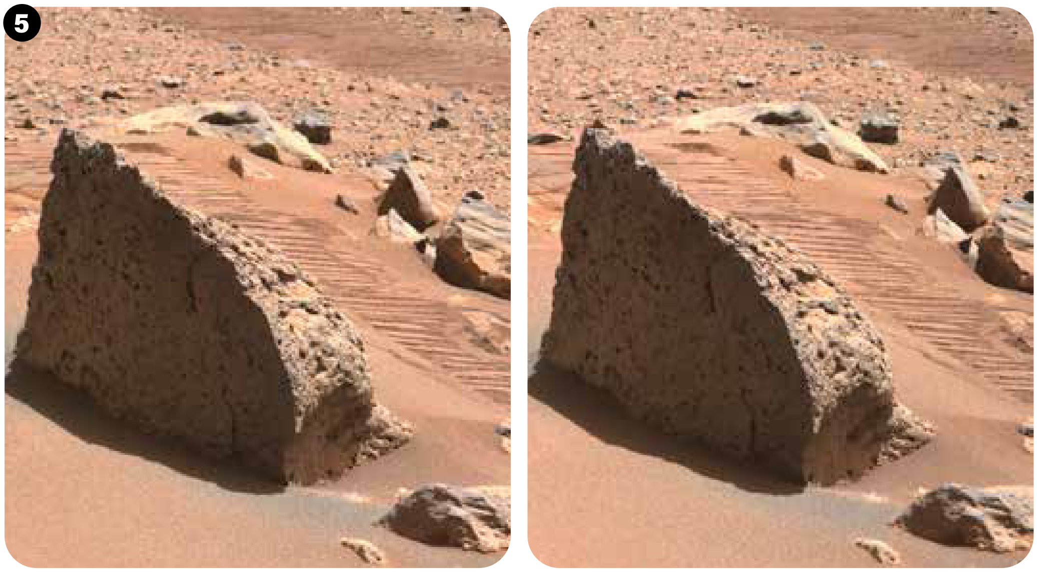

3. THE MEDIUM OF stereoscopic 3D allows the viewer to perceive the various depth layers within the scene. Here, a large quantity of rocks of different shapes and sizes extends over a vast area.

4. THIS FASCINATING CLUSTER contains particularly smooth rocks that were most likely sculpted by martian winds and sands. The bigger rock in the foreground harbors a cavity on top.

5. PERSEVERANCE'S WHEEL TRACKS stand out next to this sharp-edged rock. The magic of stereoscopy enables us to see that this spot stands on a small mount overlooking an expanse of rocks.

Using two cameras simultaneously allows us to see Mars in three dimensions. Such stereoscopic photography evokes the same sensation that a human would perceive standing on the surface of Mars.

VIEWING 3D IMAGES

There are two ways to view the images printed here in 3D. To view the images with no mechanical assistance, let your eyes relax as you look at the photos as though focusing on a point behind them. At first you will see the two images split into four; as your eyes focus at the correct distance, the middle two images will combine to create a single, crisp 3D image. The outer two images will remain on either side of the 3D image and become blurry.

Alternatively, you can use a 3D viewer, such as the OWL Stereoscopic Viewer or Lite OWL viewer, designed by Brian May. These viewers are designed for easily viewing 3D images in books, magazines, modern and vintage stereo cards, and even video or other VR content on your smartphone. You can purchase OWL viewers at **www.MyScienceShop.com**.

6. THIS PYRAMIDAL ROCK appears almost to levitate above the terrain. Looking at its shadow, especially in 3D, gives confirmation that much of the rock is actually suspended over the ground.

7. MARTIAN ROCK SHAPES frequently resemble strange and familiar objects to the human eye. This one particularly recalls the head of a dinosaur, with a clearly identifiable jawline.

8. THIS ROCK LOOKS expertly cut vertically in half. In mono, it's hard to tell whether the crack is only superficial; in stereo, it is apparent the dislocation runs all the way through the rock.

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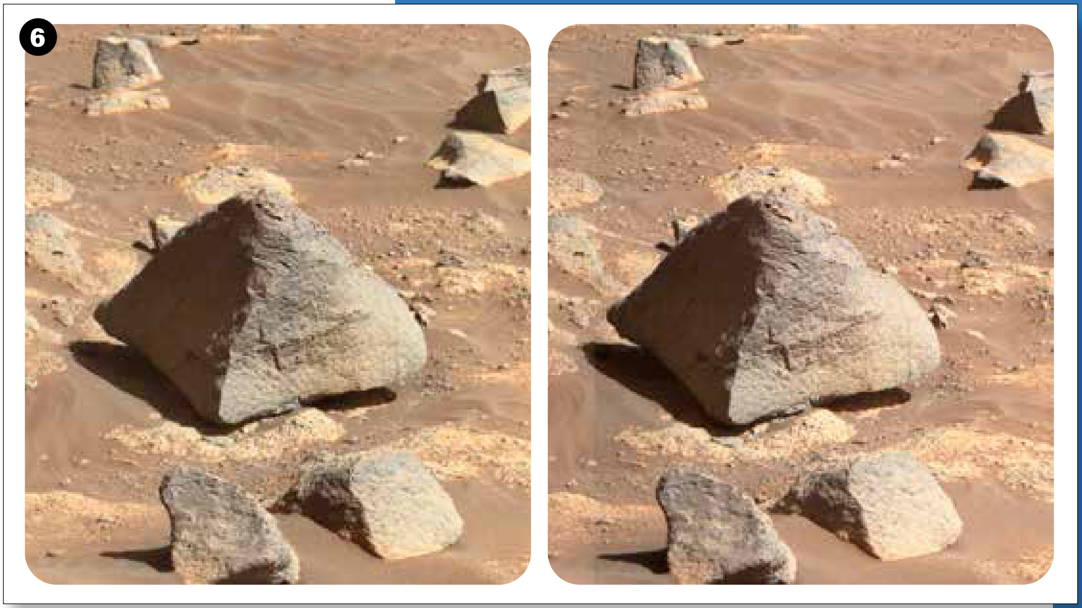

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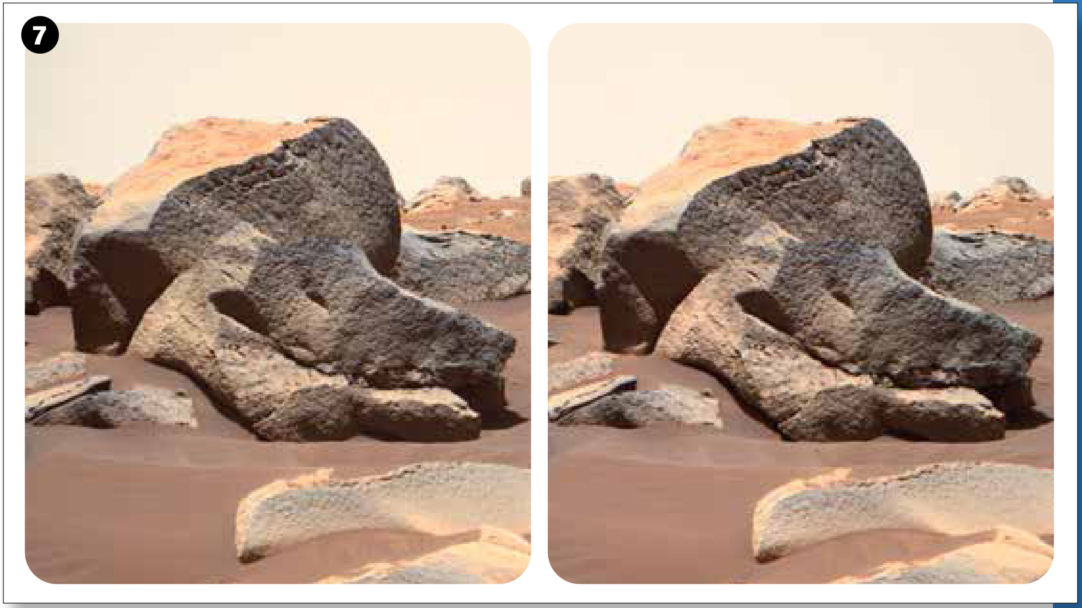

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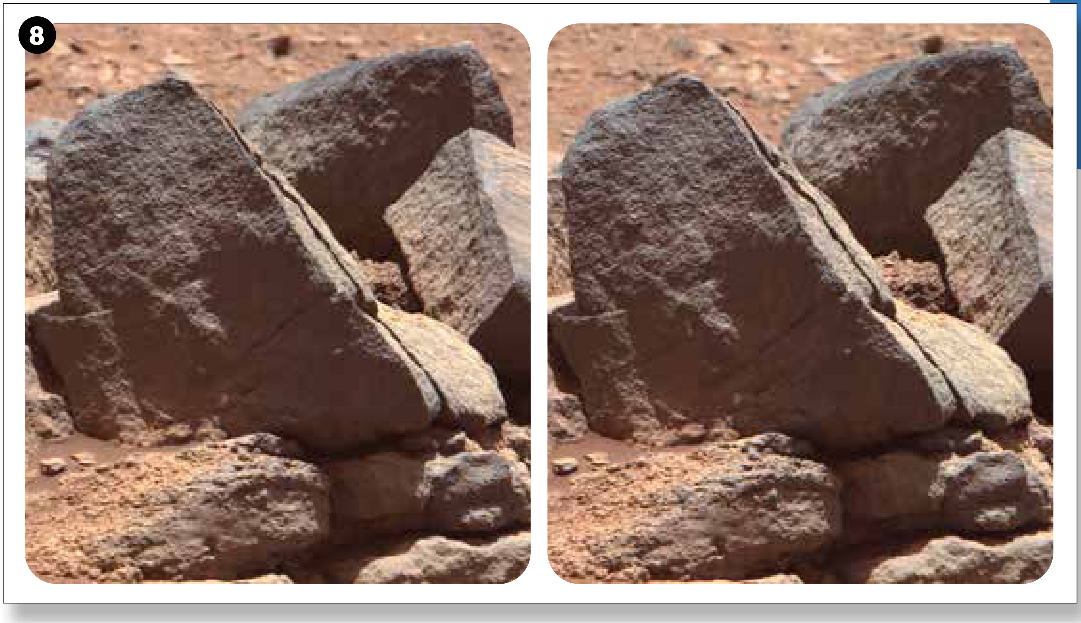
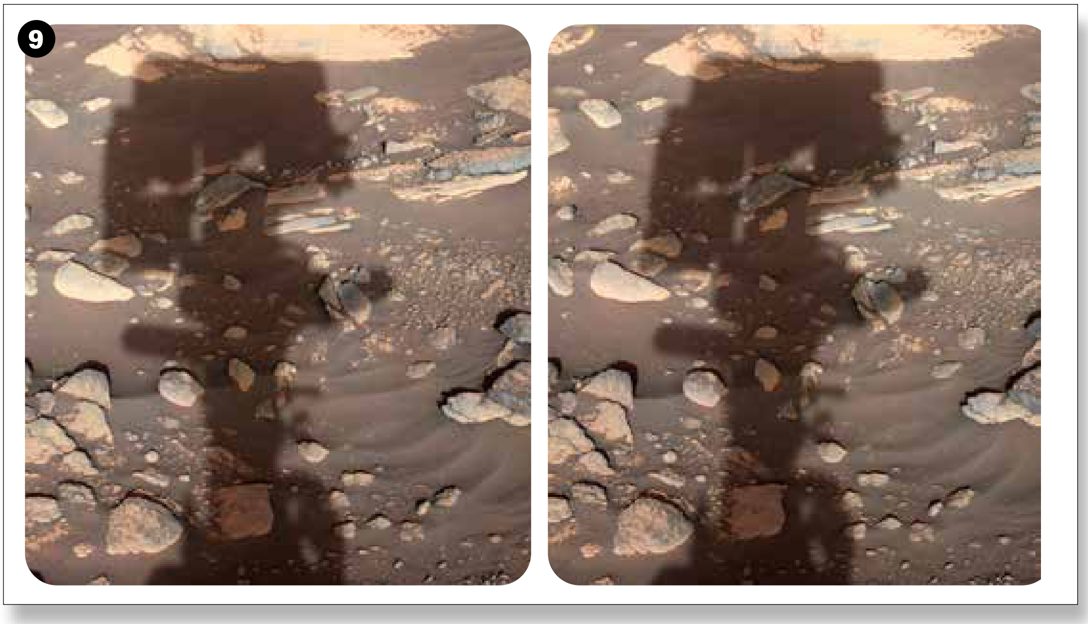
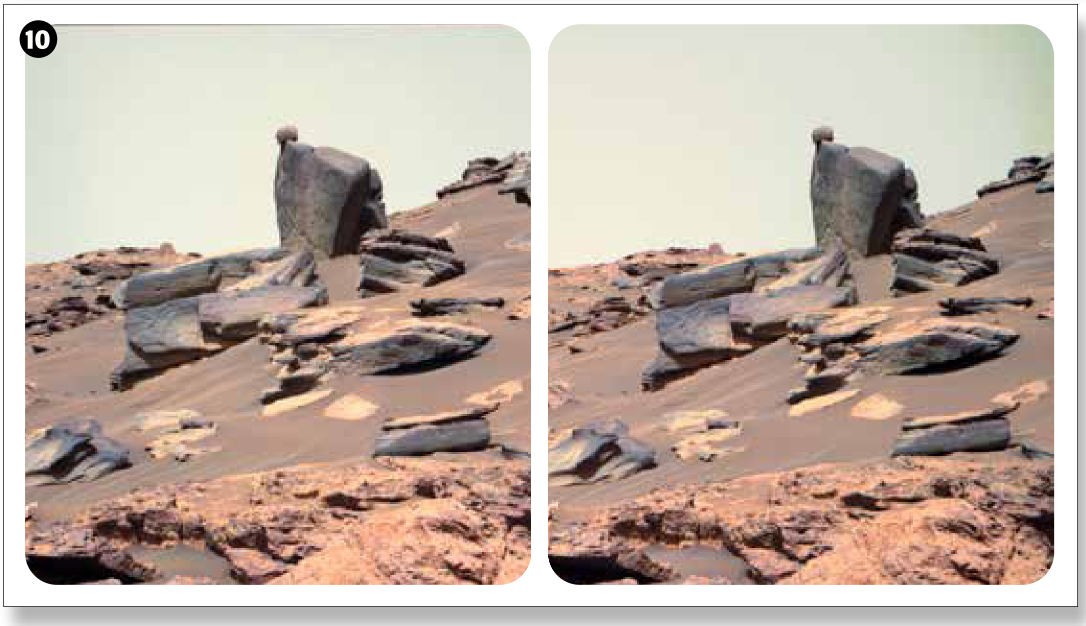


Humans have the ability to see in three dimensions thanks to evolution supplying us with two eyes. This capability was first described by English physicist and inventor Charles Wheatstone in the 1830s; he called it stereopsis, from the Greek *stereo*, meaning "solid." Wheatstone pointed out that because each of our eyes sees an object from slightly different angles, a single image can never recreate the sensation of viewing that object in real life. But by presenting each eye with separate images captured from slightly different points of view, the illusion of depth and tridimensionality can be reproduced in a photograph.

Stereoscopic photography is well suited to astronomical photos because it allows us to study and analyze a distant celestial body as if seeing it with our own eyes. Thus, it has frequently been part of space missions, bringing their achievements closer to Earth in an exciting way. From the lunar missions of the 1960s to more recent endeavors such as New Horizons and OSIRIS-REx — and, in the case of the latter two, partly thanks to the involvement of astronomer (and Queen guitarist) Brian May — various stereoscopic images have been shared with





9. THIS "SHADOW SELFIE" of the upper part of Perseverance projected onto a rocky landscape unmistakably shows the shape of its mast.

10. A SMALL, ROUNDED rock appears perfectly balanced on top of a big boulder at the center of this scene.

the world to positive reception from the general public.

CREATING STEREO VIEWS

When the initial photos from Perseverance came back to Earth, May and his brilliant collaborator Claudia Manzoni were the first to create stereoscopic images from the raw data and share them in "Stereoscopic Corner," a series of posts on the Mastcam-Z blog created by Jim Bell, the instrument's principal investigator and a planetary scientist at Arizona State University.

The first installment appeared in March 2021, when the world was still locked down. Seeing led me, an amateur stereo photographer still improving my skills at the time, to pursue the secrets of making perfect stereoscopic images from Mars.

During the challenging

ABOUT THE STEREOSCOPIST

Mary's interest in stereoscopy stemmed from Brian May's encouragement to take stereo photographs. They met in 2019 after following each other on Instagram; she was intrigued by his stereoviews and was keen to learn everything about stereoscopic photography. Since Mary's first attempts that year at stereo photography, May has provided advice and support, ultimately becoming a valued mentor.

Her work has evolved to encompass various subjects and styles, from simple stereo portraits of flowers to landscape views. In her "Modern Diableries," she takes a cheerful approach to images meant to represent souls in the Underworld, inspired by the original Diableries of the mid-19th century. In 2020 and 2021, while confined at home during the global pandemic, she experimented with developing digital stereo cards. That led her to create her "Stereo Cards from Modern Times" as well as the "Modern Diableries" series. Two of her Modern Diableries appear in the book *Stereoscopy Is Good for You: Life in 3-D* (London Stereoscopic Company, 2022).

Mary also produces handmade stereo cards and is on the leadership team for the Virtual Stereoscopic Community, an online community for stereoscopy enthusiasts. She displays her creative work on her Instagram (@maryf.3d) — a mix of captivating visual art and engaging space-related content, all showcasing her multifaceted personality and interests.

MARY FRIARGIU

11. THIS ROCK'S ROUND shape is a perfect example of the sense of full tridimensionality that appears when viewing an object in stereo.

12. TAKING SAMPLES OF rock from the surface of the Red Planet is one of the two main missions for the NASA rover. The two drill holes where Perseverance obtained samples from this rock give it the semblance of a surprised face.

13. THIS ELLIPTICAL ROCK shows two deep rifts that split the stone into three roughly equal parts.

times of the pandemic, when I found myself confined at home, I felt motivated to further develop my astronomical stereo skills. With unfailing support and encouragement from May and Manzoni, I practiced until my individual work led to an ongoing group collaboration for "Stereoscopic Corner" in December 2021.

My aim is to share these stereo images with a wider audience to show Mars from a more realistic perspective, allowing the viewer to virtually explore the Red Planet's terrain. Here is a selection of my favorite 3D images generated from Perseverance data over the last two years, from landscapes to detailed views of rocks. The scenes sometimes recall similar vistas from our own planet, but at other times present us with strange and peculiarly martian sights.

The photos can be viewed in stereoscopic 3D with the aid of an OWL Stereoscopic Viewer by placing it squarely over each stereo image. The brain, with the aid of the two lenses, will fuse the two images into one beautiful sight with a realistic sense of depth and solidity.

Mary Friargiu *is a young stereoscopist from Iglesias, on the southwest coast of Sardinia, Italy. She would like to thank Brian May and Claudia Manzoni.*

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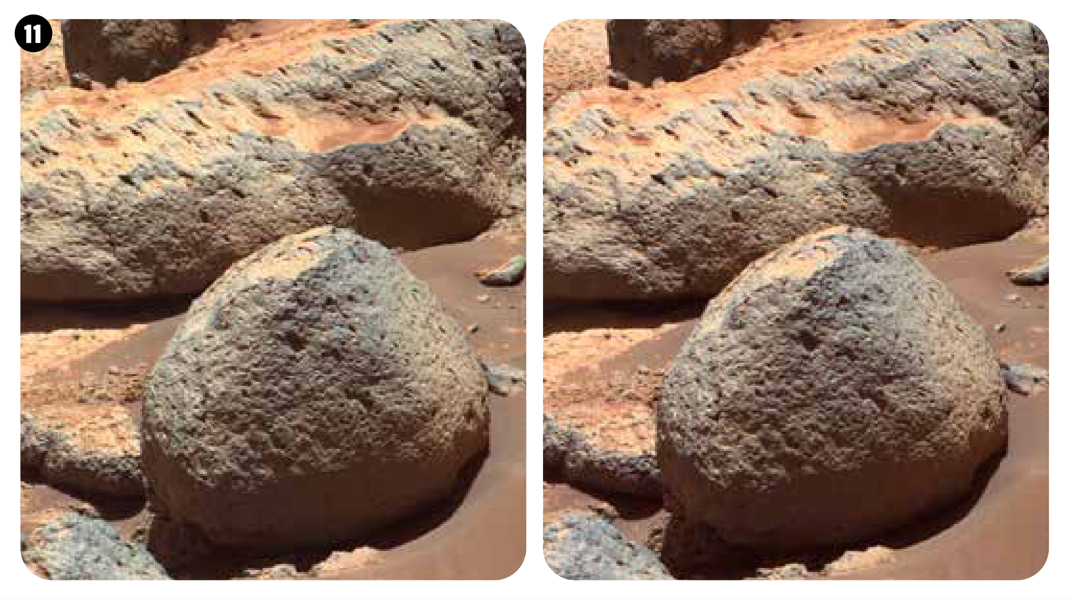

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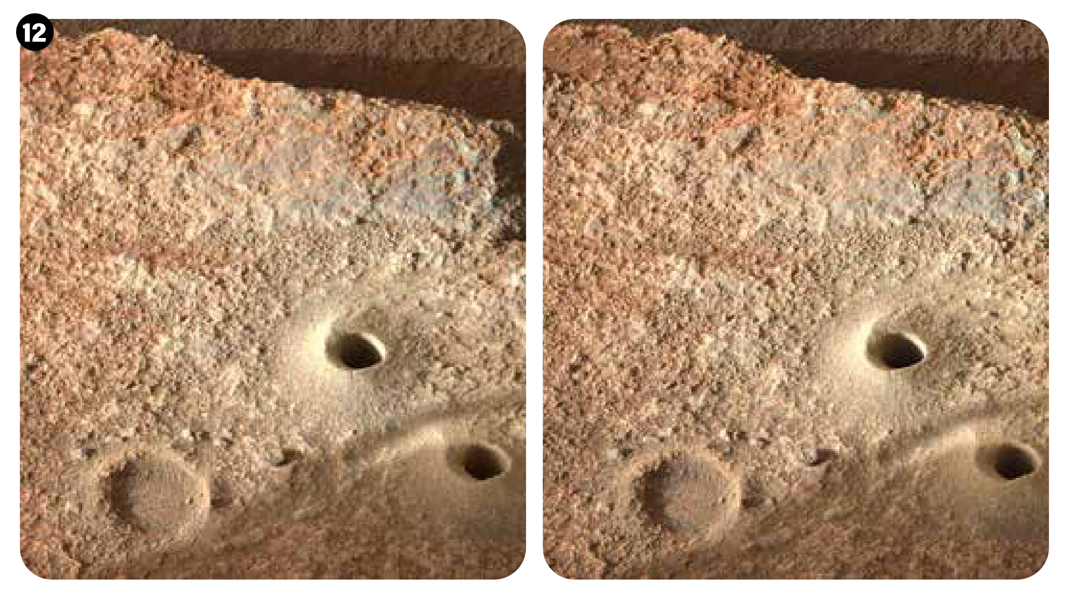

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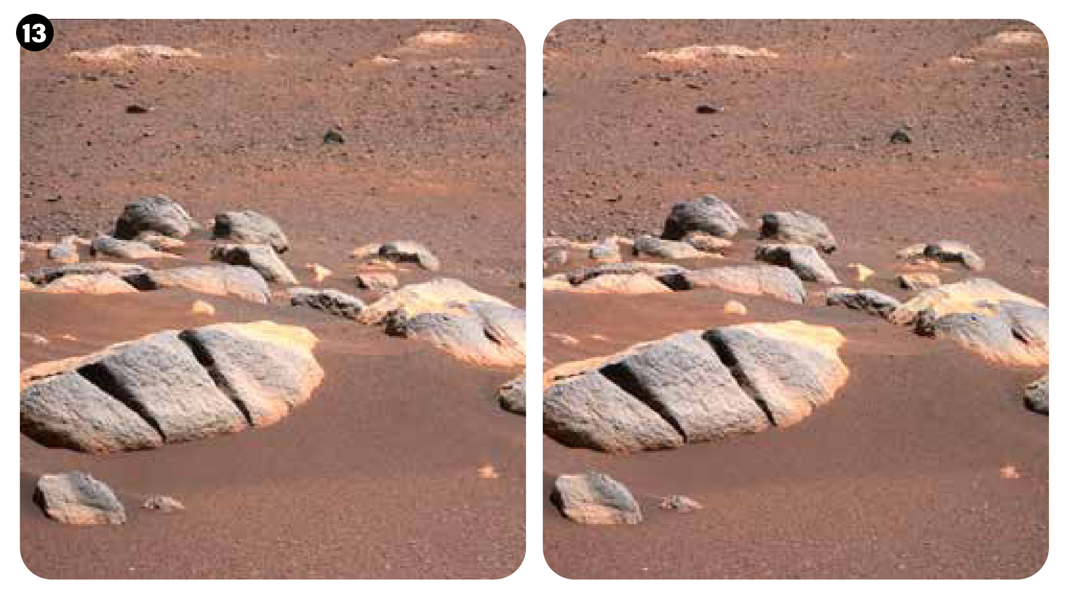


Twilight's glow

Twilight is a time when sunlight and Earth's atmosphere intermingle to produce wonderful effects. But with the anticipation of setting up equipment and making plans for observing, we often forget to watch one of nature's most beautiful spectacles, the time of transition from our busy day into the vibrant night.

What's more, understanding twilight in its different stages helps to define how we see the sky at its best. Whether you're an early riser or have stayed up all night, learning the three kinds of twilight will ensure you can catch the radiant atmospheric light show.

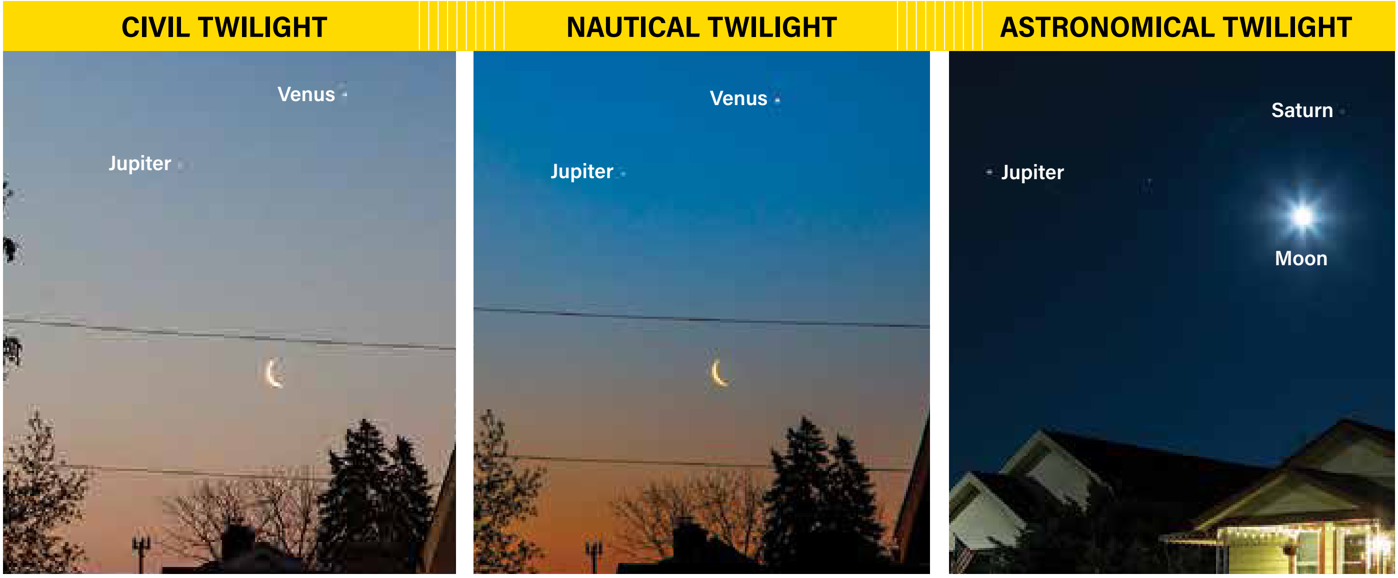
Scattered light

On a clear day, the sky can appear an intense and beautiful blue. This results from a complex interaction of sunlight and air molecules. The visible portion of the Sun's light represents only a fraction of the solar spectrum: With its energetic short wavelength, blue light is scattered more easily by dust and air molecules, such as oxygen and nitrogen, than redder light. As a result, the sky looks blue in every direction. This effect is known as Rayleigh scattering.

However, the bright blue of the daytime sky seems to fade if you look toward the horizon. This is because you're looking through more of the atmosphere at low altitudes, so sunlight travels through more air molecules and scatters even more.

As the Sun sets, this scattering effect is intensified. Now most of the Sun's light is traveling through even more of the atmosphere and blue light is further scattered away, leaving the red and orange colors. Both the Sun and the horizon start to take on a reddish-orange hue.

There are other effects at play here, too. Our atmosphere is made up of layers consisting of different densities and temperatures. These distort and refract the Sun's light unevenly, and can even cause the Sun to look flattened as it sets. When



Astronomers recognize three kinds of twilight: civil, nautical, and astronomical (left to right, as seen if the observer stays in the same location). JOHN CHUMACK (3)

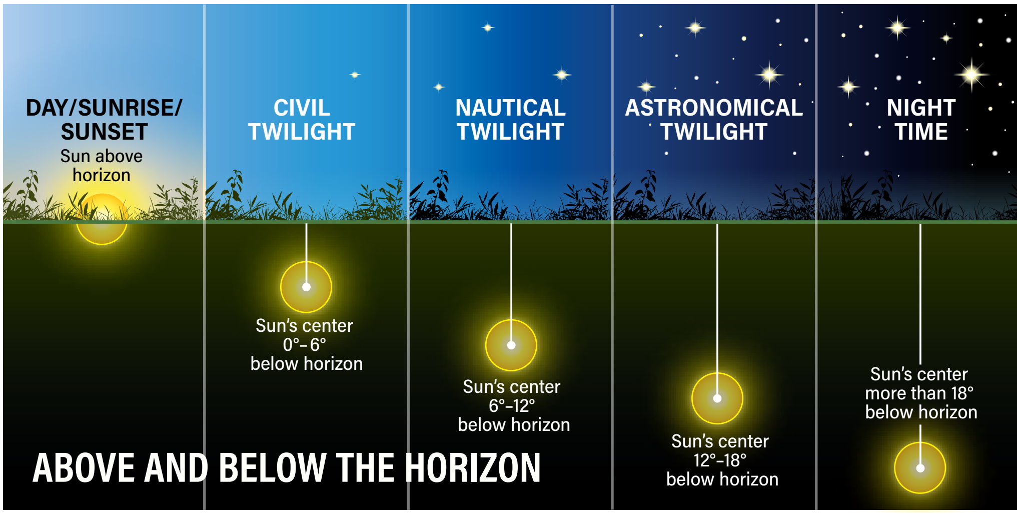
is calling

How a special time of night — and morning — helps to define astronomy.

BY RAYMOND SHUBINSKI

the Sun is just on the horizon, the light from its lower limb refracts more strongly than the light from the top of the Sun, creating the illusion of a flattened orb. (The same effect can flatten the look of the Full Moon as well.)

If conditions are just right, a brief flash of emerald may appear at the top of the flattened Sun as it sinks below the horizon. This occurs because Earth's atmosphere acts as a prism, refracting the light and splaying out its colors. The short wavelengths of violet and blue appear slightly above the Sun, while red is consigned below the horizon. The momentary green flash can result because the human eye is most sensitive to green light — but to avoid serious harm, be sure never to stare directly at the Sun.


DAY/SUNRISE/ SUNSET
Sun above horizon
CIVIL TWILIGHT
NAUTICAL TWILIGHT
ASTRONOMICAL TWILIGHT
NIGHT TIME
Sun's center 0°–6° below horizon
Sun's center 6°–12° below horizon
Sun's center 12°–18° below horizon
Sun's center more than 18° below horizon
ABOVE AND BELOW THE HORIZON

Twilight is defined mathematically; as the Sun's center travels by varying amounts below the horizon, the colors in the sky morph from a vibrant light show to a dark sky. As each type of twilight progresses, these changes signal to astronomers that fainter objects will start appearing in the night sky. *ASTRONOMY:* ROEN KELLY, AFTER AURORA BOREALIS OBSERVATORY

In twilight

Once the Sun has set, turn and face the east to witness one of the most beautiful events of twilight. A few minutes after the Sun disappears, Earth's shadow begins to rise. Each time Earth's shadow appears, its distinct round shape can be seen. In fact, it was through multiple lunar eclipse observations that Aristotle inferred — more than 2,000 years ago — that Earth is a sphere from its arclike shadow on the Moon.

As evening twilight progresses, a pink/red hue becomes visible just above Earth's shadow. Sunlight is still passing through the upper atmosphere and encounters suspended dust particles and water droplets, which scatter the long wavelengths of red light. This time is referred as the anti-twilight arch or the Belt of Venus. It is named so because in the past, writers said that the belt could cause passion and love; the pink and red hues can certainly inspire wonder.

But twilight is not solely an evening phenomenon. It occurs both after the Sun sets and before it rises. In fact, astronomers recognize three different types of twilight: civil, nautical, and astronomical. Civil dusk, or evening civil twilight, begins when the Sun disappears below the western horizon and ends when the Sun's center is exactly 6° below the horizon. Conversely, civil dawn, or morning civil twilight, starts when the Sun's center is exactly 6° below the eastern horizon. Because these precise moments can't be defined based solely on observations, they are calculated mathematically.

Civil dusk and civil dawn are meaningful for several reasons. Both these periods have not only astronomical but also cultural and religious significance. Judaism provides a striking example: The Sabbath begins at sundown when candles are lit and services start. This

> "Twilight — a time of pause when nature changes her guard. All living things would fade and die from too much light or too much dark, if twilight were not." *— Howard Washington Thurman*

TWILIGHT'S LIGHT SHOW

A spectacle of sparkling stars and shining planets dance in hues of yellow, orange, and blue, as if creating a painting made by nature during the transition from civil twilight to nautical twilight. GIANNI TUMINO

tradition stems from the book of Genesis, wherein the creation story can be translated to, “There was evening, and there was morning.”

In the evening, nautical twilight starts once civil twilight ends, and it culminates when the Sun is 12° below the horizon. Conversely, nautical dawn, or morning nautical twilight, begins when the Sun lies 12° below the eastern horizon. The term *nautical* arises because long ago, sailors out at sea depended on stars for navigation.

Evening astronomical twilight begins once the Sun's center is 12° below the horizon. For most people, this period appears like night. From a good site, the sky looks dark and full of stars. So, you might ask, if the sky appears so dark, why bother defining this last period of twilight? During astronomical twilight, Earth's atmosphere can refract sunlight, scattering some skyward. But when the Sun reaches 18° below the horizon, the sky is truly dark. We're immersed in pure night. Faint astronomical objects are visible in all their glory. Later, when the Sun reaches 18° below the eastern horizon, astronomical dawn begins and the truly dark sky begins to disappear.

The three types of twilight are defined through mathematical equations relating to the position of the Sun. Their timing and duration can vary greatly depending on two main factors: where you are on Earth and the time of year, which is directly related to the Sun's position on the ecliptic (the orbital plane of Earth around the Sun). The ecliptic is tipped 23½° with respect to the celestial equator (the same plane as the equator on Earth). Depending on the date and the observer's latitude, the Sun may appear to set at a steep or a shallow angle relative to the horizon. For example, at Earth's equator, the Sun always rises roughly due east and sets roughly due west, and is directly overhead (90° high) at midday. Because the Sun sets and rises perpendicular to the horizon at the equator, civil twilight lasts only about 24 minutes each day of the year.

In other locations, the angle at which the Sun slides below the horizon increases or decreases depending on the season. The summer solstice twilight lasts longer than the twilight at the winter solstice. Closer to the North and South poles, twilight is affected even more. The Arctic and Antarctic circles experience a period of prolonged twilight, sometimes lasting weeks. At latitude 68° north or south, depending on the season, the Sun may not rise or set at all.

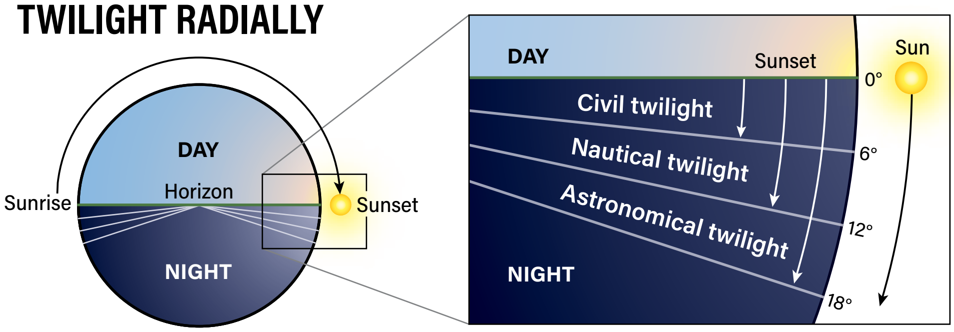
Treasuring twilight

Poets, painters, and photographers have long treasured the mellow light of twilight, when the sky softens and deepens into a glow, or gently brightens as sunrise approaches.

Howard Washington Thurman, a prominent author and philosopher, wrote of twilight as “a time of pause when nature changes her guard. All living things would fade and die from too much light or too much dark, if twilight were not.”

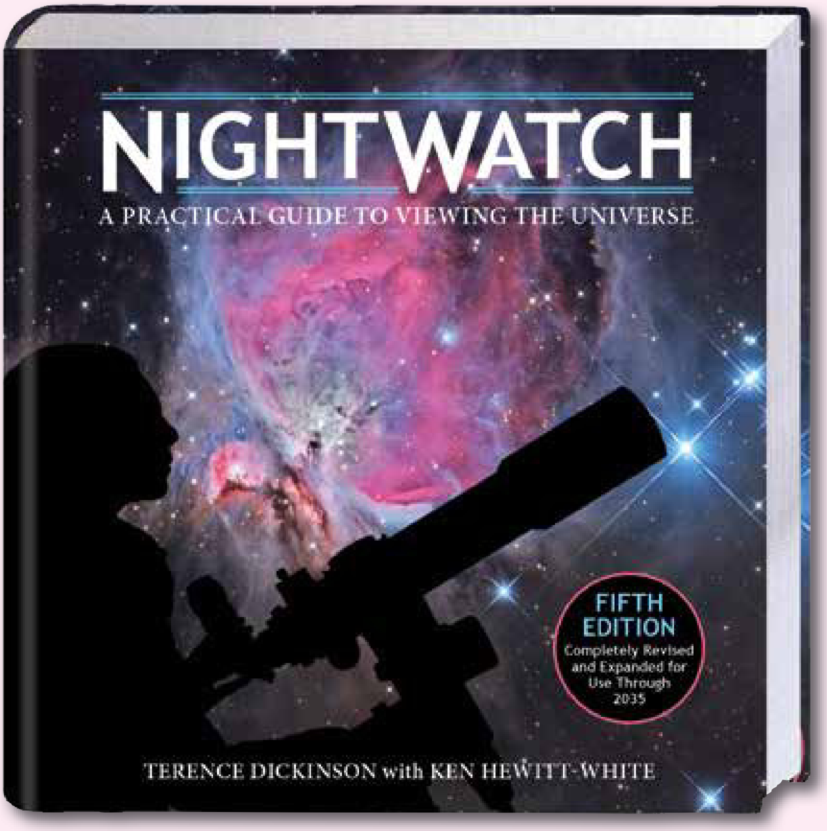
Raymond Shubinski *is a longtime contributing editor of* Astronomy *magazine who loves recovering the lost ephemera of astronomy.*

UNDERSTANDING TWILIGHT RADIALLY



This radial depiction shows how the Sun's changing location defines each type of twilight. (Note: not drawn to scale.) *ASTRONOMY:* ROEN KELLY

At last! The stunning 5th edition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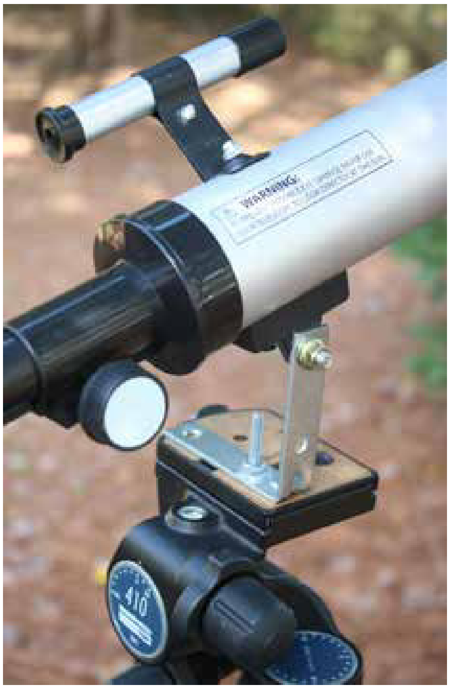
TOY TELESCOPE TRYOUT

When it comes to telescopes, you get what you pay for. PHOTOGRAPHS AND TEXT BY KEN WILSON

THE BOX SAID "TELESCOPE." The price tag said "$15." There was a whole pallet of them neatly stacked at the back of my local Five Below store. "Must be a toy," I thought. Except the box said "This is not a toy." Oddly, the package sported no brand name, not even a pseudo-brand like Big Bang Hubble, Jr. Just "Telescope."

"Ah," I thought. "Must be another one of those terrible telescopes that kills someone's interest in the hobby and winds up gathering dust in a closet." My next thought was, "How bad could it really be?" I bought one to find out.

The telescope the author reviewed seemed like a deal at $15.



One of the main problems with this telescope was the lack of azimuth motion.

The specs on the packaging were promising. There was no high-power hype. Just 20x and 66x. The diameter (50mm) and focal length (400mm) were clearly labeled. The box photo of the scope showed a finder scope, star diagonal, and cellphone holder. There was even a prominent label warning against looking at the Sun through the telescope.

Another good sign was a lack of the usual color images of galaxies and nebulae implying vistas as good as the Hubble. Instead, there were just a couple of Moon images and a bird photo. There were also three line drawings: the Big Dipper, Saturn over a mountain, and a cow flying past the Moon!

The scope itself

Inside the box, I found a well-packed tube assembly, a tabletop tripod, instructions, and a plastic bag of parts that included the finder scope and two eyepieces enclosed in protective plastic capsules. Both eyepieces have nonstandard, 0.93-inch (23.6 millimeters) diameters and are made of plastic. The eyepieces are ancient Huygenian designs with inherent narrow fields and chromatic aberration, an optical problem where red light and blue light don't focus at the same place.

Assembly was quick and straightforward, but it immediately revealed a fatal flaw. Even a novice stargazer (and certainly a telescope designer) knows that a telescope mount needs to move in two perpendicular directions to aim at celestial objects. Simple telescope mountings move the tube up and down (in altitude) and back and forth parallel to the horizon (in azimuth). This scope has only the altitude motion!

The tube attaches to the tripod via a plastic pivot hinge. A metal bolt passes through holes in the hinge and a hex nut secures the tube to the tripod. The bolt and nut provide adjustable friction for the altitude motion. Unfortunately, the only way to adjust the friction is with an included metal wrench. It would have been better to use a wing nut or a threaded clamping knob.

Cumbersome as the altitude adjustment is, the lack of azimuth adjustment is a deal-killer. The only way to aim the telescope in azimuth is to skitter the whole tripod around on the surface it sits on. This flaw makes the telescope almost impossible to aim at an object, much less track it. This also restricts the altitude range when the tube is attached in one of two possible configurations. One position places the tube directly over one of the tripod legs, which limits tilt — the tube can only reach about 45° in altitude before it hits the leg. Should you attach the tube 180° around to clear the leg, you'll find that you can't use the cellphone attachment. If you do so, the mount balance shifts so much that the tripod topples over!

Another huge flaw is the finder scope. A finder is supposed to have a wide field of view (between 5° and 8°) to help aim the main scope. Finders also usually have crosshairs in them to let the observer center on the target object. This finder has no crosshairs. Furthermore, its field of view is only about 2°, and its 13 mm objective (good finders have 50 mm objectives) gathers very little light. Worst of all, this finder has no way to adjust its alignment with the main telescope. That makes it all but useless.

Under the sky

Without a usable finder or a proper mount, testing the telescope optics proved a real challenge. I wound up making a bracket to attach just the tube to a camera tripod that had both altitude and azimuth controls so I could aim it. Sighting along the main tube and using the lowest-power (20x) eyepiece, I was eventually able to view a few bright celestial objects.

My first target was the Moon. I wasn't surprised to see that it had pronounced colors along its edges — a telltale sign of chromatic aberration, the bane of cheap refractors. Nonetheless, it was fairly easy to find the Moon. Although the power was low, the broad lunar features were visible. I could even see a few of the larger craters. Unfortunately, I noticed a lot of glare. Closer inspection of the interior of the telescope and eyepiece tubes revealed that both had shiny, metallic interiors! A few cents' worth of flat black paint would have gone a long way to killing the internal reflections.

This telescope was made of so few parts that assembling it was easy.

Next, I aimed at Jupiter. I could see the four largest moons but no detail on the planet's disk. My next target, Saturn, was disappointing. Neither eyepiece resolved its rings. All I could make out was a football-shaped blob.

I could plainly see the Orion Nebula (M42) but any detail was washed out by the scattered light. The Pleiades (M45) fit nicely in the 20x eyepiece's field, but each star was a miniature rainbow instead of a pinpoint.

Lastly, I tried out the cellphone adapter. It fits over the eyepiece holder and allows you to take pictures through the telescope. Aligning it to the eyepiece took some fiddling. Eventually I was able to snap pictures of the Moon and the two planets. It wasn't easy because the adapter ring uses friction to secure it on the eyepiece holder, and that wasn't always enough to keep my phone in place as I aimed the telescope.

Alas, like so many cheap telescopes, this one cannot be recommended. The plastic optics are poor, and the mount and finder scope are useless. On second thought, I can think of one use for this telescope. If you teach a "how to buy a telescope" class, this toy is an excellent example of what not to buy and why.

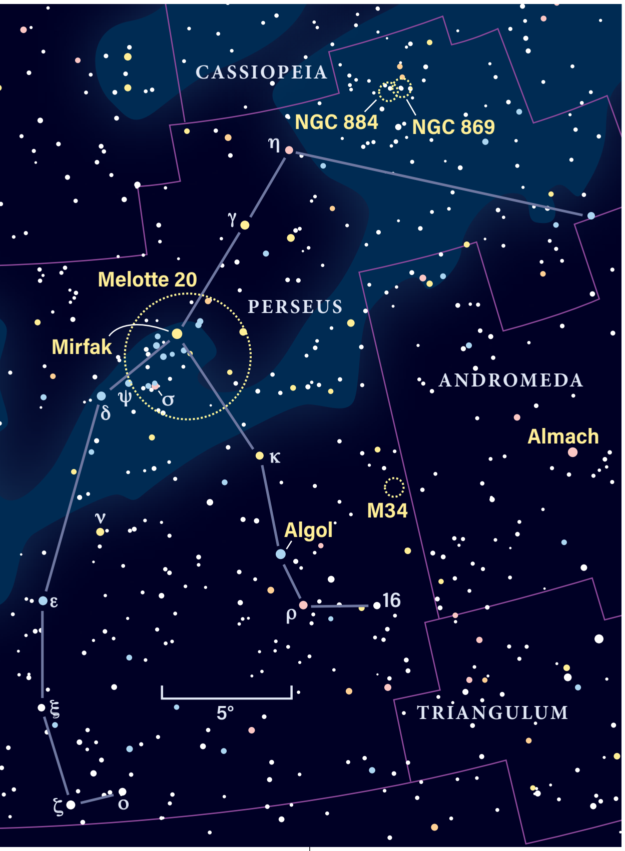
The assembled scope was small, light, and essentially useless.

Ken Wilson *is a retired planetarium director who has been toying with telescopes since 1968.*

BINOCULAR UNIVERSE

Heroic treasures

See a Demon Star and other epic night sky sights.



Perseus contains numerous bright stars and clusters. *ASTRONOMY: ROEN KELLY*

Perseus, the Greek mythological hero, is probably best known to amateur astronomers as the home of the beautiful Double Cluster, NGC 869 and NGC 884. The pair is striking through all binoculars and is always a first stop for me whenever I head out this time of year. How Charles Messier could have missed them, and yet included some far greater challenges in his catalog, is beyond me.

But there is more to enjoy within the limits of Perseus than just the Double Cluster. This month, let's explore three other targets that await us.

Our first stop is hiding in plain sight. Focus on 2nd-magnitude yellow supergiant Mirfak (Alpha [α] Persei), the constellation's brightest star, and let your eyes wander around the field. See all those other stars? Many of them belong to open cluster **Melotte 20**, an entry in the catalog of 245 star clusters (and a few renegades) published by British astronomer Philibert Jacques Melotte in 1915. Melotte 20, better known as the Alpha Persei Moving Cluster, is made up of about 50 stars (although some sources cite 10 times that many), including Delta (δ), Sigma (σ), and Psi (ψ) Persei. The cluster's center lies south of Mirfak and spans an incredible 3.5° of sky.

Looking slightly east of Mirfak, the stars of the cluster seem to wander to the southeast, then back toward the west, and finally eastward again toward Sigma, Psi, and Delta. Garrett Serviss commented on this in his 1888 book *Astronomy With an Opera-Glass*: “The field about Alpha is one of the finest in the sky for an opera-glass. Stars [are] conspicuously arranged in curving lines and streams. A host follows Alpha from the east and south. … They are grouped, as it were, behind their leader.”

As we enjoy the star-scattered view around Mirfak, a demon sits nearby. **Algol** (Beta [β] Persei) was nicknamed the Demon Star by the ancients because they imagined it as the evil eye of Medusa the Gorgon. While other stars shine steadily, Algol appeared to be winking. Of course, today we understand that the winks are not due to some supernatural force, but rather are caused by Algol's binary nature. Algol is the best-known eclipsing binary star in the northern sky. While it usually shines steadily at magnitude 2.1, it dips to magnitude 3.4 for about 10 hours every 2.87 days. That's when the system's type B primary star is partially eclipsed by a fainter type G companion, as seen from Earth.

Watching Algol “wink” through binoculars is a fun way to show that we live in a dynamic universe. First, you'll need a chart to compare its appearance to nearby stars that don't change in brightness. You'll find a good one at www.freestarcharts.com/algol.

Next, you need to know when to look. At lower left is the timetable for Algol's minima visibility at night from North America over the next month and a half. Note that these times mark the midpoint of the 10-hour eclipse.

Messier may have missed the Double Cluster, but he did include another striking Perseus target that we can enjoy through our binoculars. He saw it in August 1764: **M34** is nestled 5° northwest of Algol and 7° east of Almach (Gamma [γ] Andromedae). It lies about 1,500 light-years away and is a magnificent binocular target indeed. You can't miss it.

M34 spans half a degree of sky, the same as the Full Moon. Sixty stars, most shining between 7th and 13th magnitude, lie within. Through my 10x50s, I count a dozen points bathed in the misty glow of fainter, unresolved stars. A tight knot of suns highlights the cluster's center.

Giant binoculars add to M34's beauty. In their book, *Sky Vistas* (Springer 2004), authors Craig Crossen and Gerald Rhemann described the cluster stars as forming “a partial ellipse, open to the east-southeast. … The ellipse is enclosed by a large ‘box’ of about a dozen magnitude 7.5–10 stars.”

Questions, comments, suggestions? Drop me a line via my website, philharrington.net. Until we meet again next month, remember that two eyes are better than one.

ALGOL MINIMA (2023)

Date	Time
Nov. 1	10:12 P.M. EDT
Nov. 4	7:01 P.M. EDT
Nov. 16	5:17 A.M. EST
Nov. 19	2:06 A.M. EST
Nov. 21	10:55 P.M. EST
Nov. 24	7:44 P.M. EST
Nov. 27	4:33 P.M. EST
Dec. 9	3:49 A.M. EST
Dec. 12	12:38 A.M. EST
Dec. 14	9:27 P.M. EST
Dec. 17	6:17 P.M. EST

BY PHIL HARRINGTON
Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

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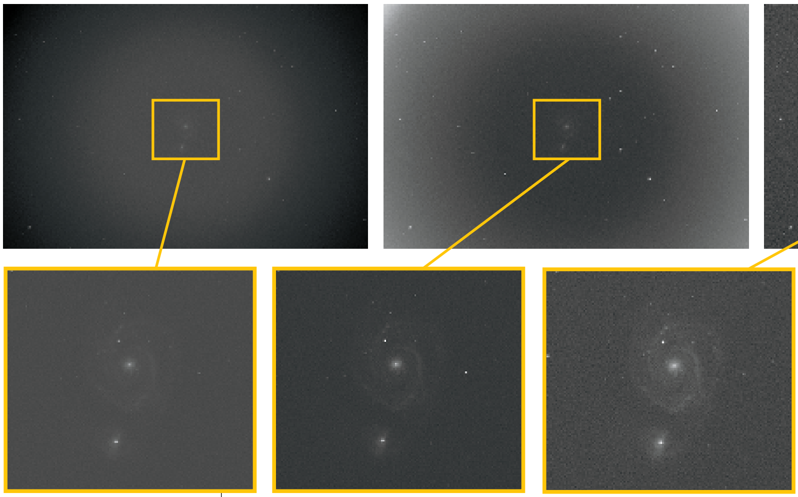
Coming to terms

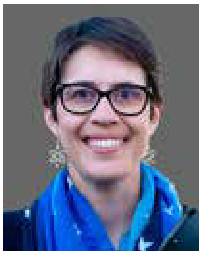
Learning astrophotography requires a bit of jargon.



LEFT TO RIGHT: An original, uncalibrated subframe of the Whirlpool Galaxy (M51).

The same image calibrated with flats only, no darks (or flat darks).

The image properly calibrated with flats and darks. MOLLY WAKELING



BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She is pursuing her Ph.D. in nuclear engineering.

When you're starting out in astrophotography, the myriad technical terms can be daunting. Gain? Offset? Flat darks — or is it dark flats? Let's clear up some common areas of confusion.

We'll start with gain. Setting the gain value affects a camera's electronic gain, which is reported in electrons per analog-to-digital unit, or e^-/ADU. A common belief is that adjusting the gain changes the sensitivity of the camera. However, it's more accurate to say that it changes the way the camera quantizes light as it converts photons into a digital signal.

A camera sensor converts photons to electrons, which are then collected and read out at the end of the exposure. The amount of charge is converted to digital units of pixel brightness, from black to white. The scale depends on the camera's bit depth: A 12-bit sensor has a range of 0 to 4,095 ADU, while a 16-bit sensor has a range of 0 to 65,535 ADU. Shooting at unity gain means 1 electron = 1 ADU. At low gain, it will take multiple electrons to add 1 ADU to a pixel's total count. At high gain, each electron adds multiple ADU to that pixel.

A higher gain reduces the well depth, or how many electrons it takes to saturate the pixel. This gives the appearance of higher sensitivity and allows for shorter exposures at the expense of dynamic range — the range of brightness values the camera can record in a single shot. Lower gain allows you to use the full well depth of the pixel, making smaller gradations between brightness values and thus increasing contrast and dynamic range; however, you lose signal when not enough electrons accumulate to step one whole ADU. If you're not sure where to start, unity gain is a good compromise.

Offset is the amount of charge that is preloaded into the pixels to prevent them from reporting zero. This avoids losing any small amount of signal. There is not necessarily an optimum offset, but you do need to determine how large an offset is sufficient. At your camera's shortest exposure setting and while covered, adjust the offset until the histogram curve separates from the left edge of the histogram, indicating that no pixels are reporting zero.

Dark calibration images help reduce the noise that accumulates from heat and electronics during a long exposure. This can't remove the random shot noise — the statistical noise inherent to capturing low numbers of photons. But it can reduce fixed-pattern noise (caused by variations in pixel response, leading some pixels to consistently read brighter or dimmer) and hot pixels (defective pixels that read much too bright).

To create a master dark, cover the camera and take at least 10 shots with the same exposure time, camera temperature, gain, and offset as your light frames. The camera does not need to be on the telescope. I usually take 50 to 100 darks for better statistics, as you will be averaging (stacking) the frames to create a master dark. I keep a darks library for different temperatures and settings. (Bias frames are no longer necessary for today's modern CMOS cameras, and can actually cause problems instead.)

Flat frames correct for vignetting (darkening of the corners) and dust spots. These don't need to be taken at the same temperature nor exposure time as your light frames, but they do need to be at the same gain and offset, and the camera must be on the telescope in the same orientation and focus. A properly exposed flat image should have the histogram peak roughly centered. For color cameras, it can be difficult to get all three red, green, and blue peaks in the center; just make sure they are not falling off the left or right sides of the graph. Adjust the exposure time to change the histogram peak location.

Flat darks are dark frames for your flats — just like you use a master dark to calibrate your lights. These are not always necessary, but if you experience problems with flats appearing to overcorrect your lights, try calibrating your flats with flat darks. These, like dark frames, can be taken off the telescope if necessary, and should be around the same temperature and have the same exposure time as the flats.

Now that you are armed with knowledge of common astrophotography camera terms, you are ready to take great astrophotos. Bring on the photons!

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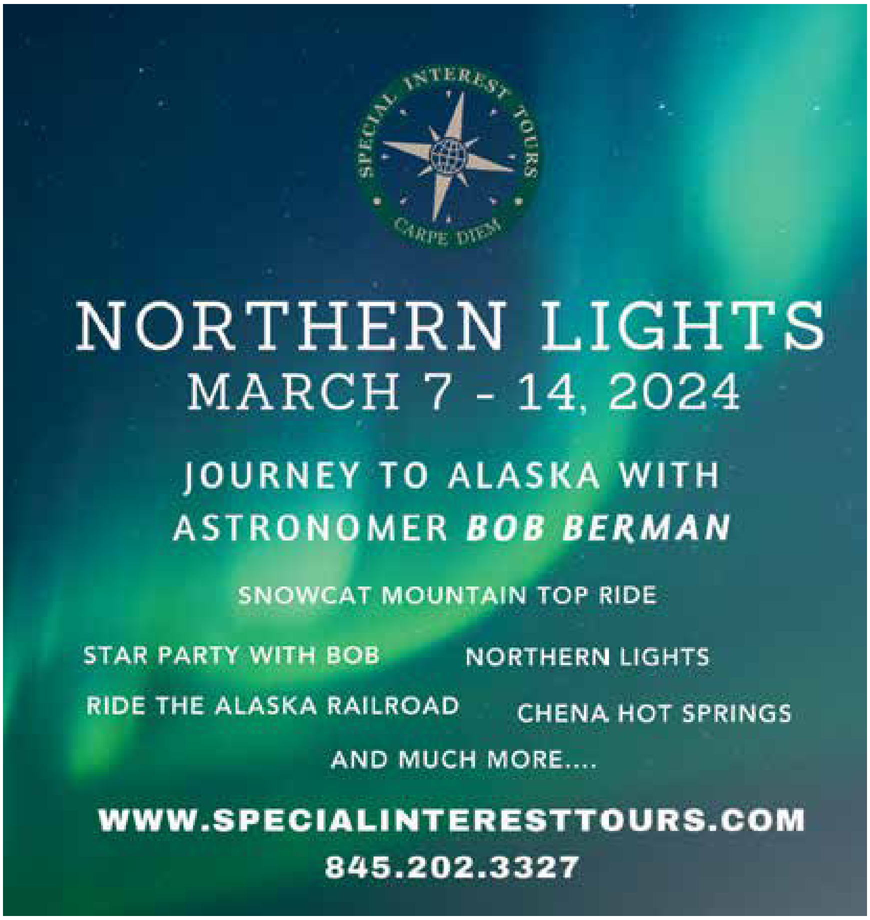

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At particle colliders like the Large Hadron Collider, researchers tap into Einstein’s equations in the search for dark matter particles. DANIEL TURBASA/DREAMSTIME.COM

Matter and energy

Q DOES EINSTEIN’S EQUIVALENCE OF MATTER AND ENERGY, $E = MC^2$, HOLD TRUE FOR DARK MATTER AND DARK ENERGY?

Gary George
Cincinnati, Ohio

A Yes — in short, this is true for all forms of matter and energy, including dark matter and dark energy. But there are some important details to consider.

$E = mc^2$ is a special case of the full equation $E^2 = (mc^2)^2 + (pc)^2$. The term pc represents the kinetic energy of an object, which means the familiar $E = mc^2$ is only exactly true for objects at rest or in the same rest frame, where the momentum p is zero. That’s why the mass (m) in the equation is also referred to as rest mass.

Usually, the part of the equation containing the rest mass is much larger than the kinetic energy. Then $E = mc^2$ is a good approximation for everything that doesn’t move at a significant fraction of the speed of light. And speaking of light, photons (the particles of light and electromagnetism) are the other extreme of the full equation. They have no rest mass (so that term becomes zero) but they still have momentum and thus energy.

The fact that kinetic energy is also part of the total energy of particles is exploited by scientists at particle accelerators, like the Large Hadron Collider at CERN. By accelerating particles to nearly light-speed, new particles can be created in head-on collisions that have even more rest mass than the original ones. Researchers use this method to search for dark matter particles by trying to create dark matter from the mass and energy of other particles.

The equation even holds true for dark energy. The simplest way to understand dark energy is as the energy held by the vacuum of space itself. So, even in the most perfect vacuum without a single particle of matter, there is some tiny amount of energy. For example, the dark energy content for a sphere enclosed by the Moon’s orbit would only equate to a mass of about 3 pounds (1.4 kilograms), which is easily overshadowed by pretty much everything else within that volume. However, as the universe is mostly a lot of empty space, this tiny amount of energy held by the vacuum of space amounts to the majority of the total energy content in the universe. Due to the odd properties of dark energy, the gravitational pull generated by its mass equivalent is easily overcome by its negative pressure, which is the force driving the accelerated expansion of the universe.

Christoph Saulder
Cosmologist, Korea Astronomy and Space Science Institute,
Daejeon, South Korea

Q DOES GRAVITATIONAL ATTRACTION TRAVEL THROUGH SPACE AT A MEASURABLE RATE, OR IS IT INSTANTANEOUS?

Thomas L. Richie
Rockville, Maryland

A In Isaac Newton’s theory of gravity, the gravitational attraction between two objects is proportional to the product of their masses divided by the distance between them squared, and this attraction acts with no delay or lag. From this, you can derive all sorts of characteristics of celestial objects, including the motion of planets around the Sun. These orbital predictions matched observations perfectly, which led us to believe for centuries that gravity traveled instantaneously.

All this changed at the start of the 20th century with Einstein’s theory of special relativity, which states that the distances between objects and the passage of time depend on the relative motion of an observer. This is inconsistent with Newton’s gravitational law and the observed orbits

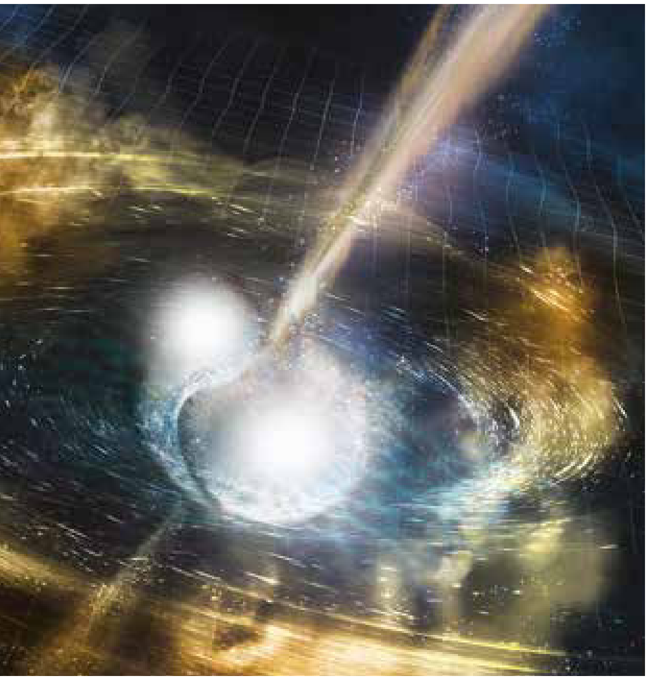
ABOVE: This composite, featuring two images taken by the Curiosity rover, shows views on April 8, 2023, at 9:20 A.M. (right) and 3:40 P.M. (left) local Mars time. NASA/JPL-CALTECH

of the planets. This led Einstein to develop general relativity, which describes both relativistic motion and gravity. In general relativity, gravity travels at the speed of light instead of instantaneously. Once relativistic effects are accounted for, general relativity also accurately predicts the orbits of planets around the Sun.

Einstein published the general theory of relativity in 1915 and since then, it has spectacularly passed every test we have thrown at it. The simplest and most convincing observation that gravity travels at the speed of light came in 2017, when both gravitational waves and light were observed from a merger of two neutron stars. Despite traveling more than 100 million light-years, the two signals arrived at Earth only 1.7 seconds apart! This means the speed of light and the speed of gravity differ by no more than 1 part in a quadrillion — in other words, they differ by no more than 0.0000000000001 percent.

Sam Young

Marie Skłodowska-Curie Research Fellow, Lorentz Institute, University of Leiden, Netherlands



BOTTOM LEFT: An artist's concept shows neutron stars merging in a kilonova seen with both light and gravity in 2017. The observation showed that both light and gravity travel at the same speed. NSF/LIGO/SONOMA STATE UNIVERSITY/A. SIMONNET

Q | WHAT IS "LOCAL MARTIAN TIME"?

Dennis W. Gordon

Waunakee, Wisconsin

A | Mars doesn't yet have an official calendar or time zones like we have on Earth. The only officially designated time unit on the Red Planet is the sol, which is defined like the day is on Earth: one full planetary rotation on its axis. But for planning and data analysis, scientists and engineers working on Mars missions still need some way to figure out what time it is, not here on Earth, but there at a particular place on that planet. So, just like on Earth, we can divide a martian sol into different time zones — local martian times, if you will.

In order to keep Mars time familiar to those of us back on Earth, one can tally time on each sol using a Mars clock with 24 "Mars hours." These Mars hours are often called "solar hours" because they track the Sun's position in the Red Planet's sky. For example, 12:00 noon local Mars time is when the Sun is highest in the sky at that specific place. A new sol begins at 12:00 midnight local Mars (solar) time.

Because Mars rotates on its axis just a little bit slower than Earth does, though, a sol on Mars is 2.75 percent longer than a day on Earth: 24 hours 39 minutes 35 seconds. So expressed in Earth time, on Mars each solar hour is 1 hour 1 minute 39 seconds (1⁄24 of a sol) long, each solar minute is 61.65 seconds long, and each solar second is 1.0275 seconds long.

This small difference makes life challenging for those of us back on Earth living on "Mars time" vicariously through our lander and rover avatars. For example, if we need to start rover operations three hours after local sunrise every sol, and we start at noon Earth time on a Monday, we'll start around 12:37 P.M. on Tuesday, then 1:15 P.M. on Wednesday, 1:52 P.M. on Thursday, etc. Within a few weeks, we're working late-night shifts (Earth time), and then a few weeks later we're back into regular workday hours. It's confusing and physiologically challenging to live on Earth and work on local martian time — but also great fun!

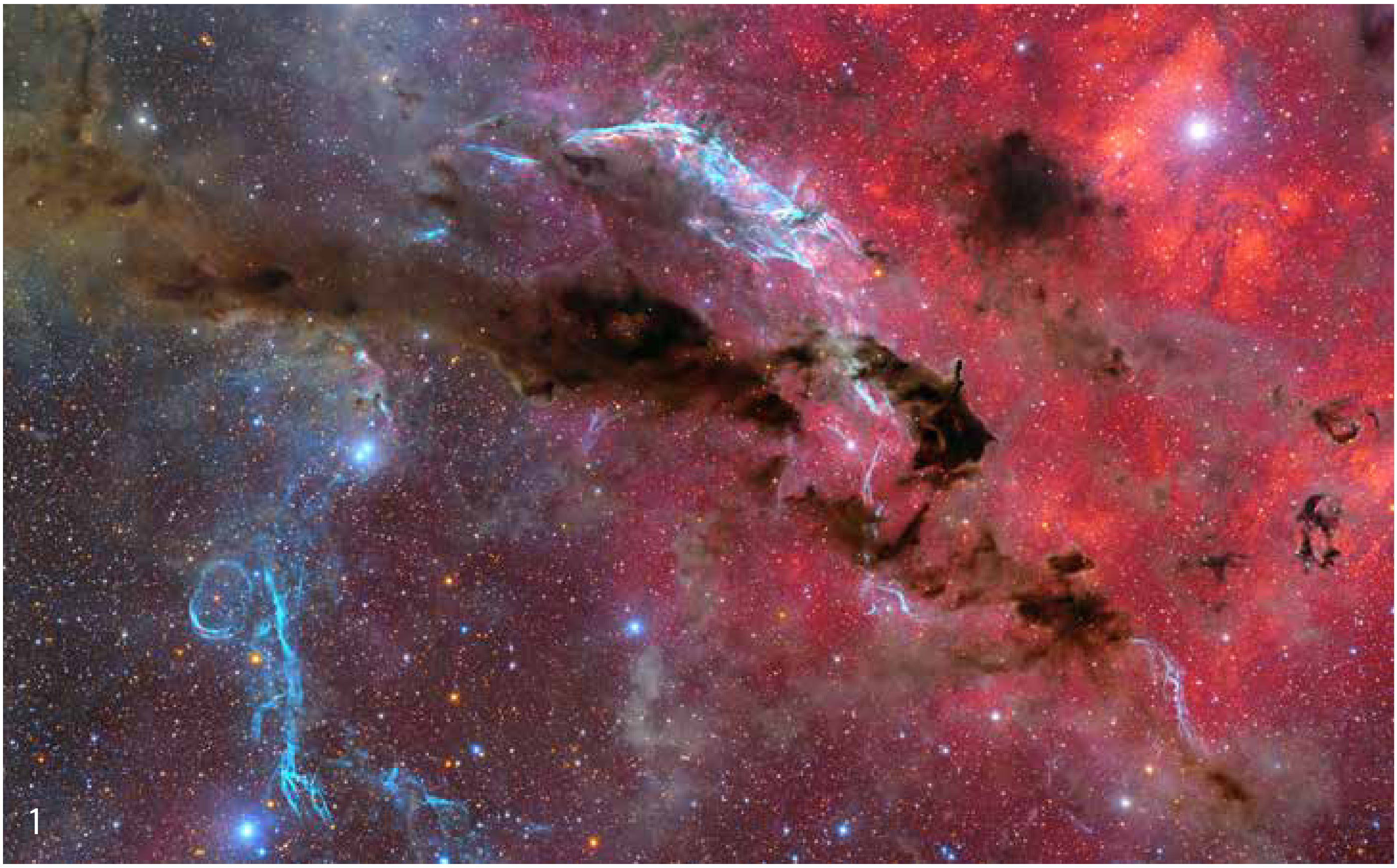
Jim Bell

Deputy Principal Investigator for Science for the Mars Science Laboratory Mastcam, Arizona State University, Tempe, Arizona

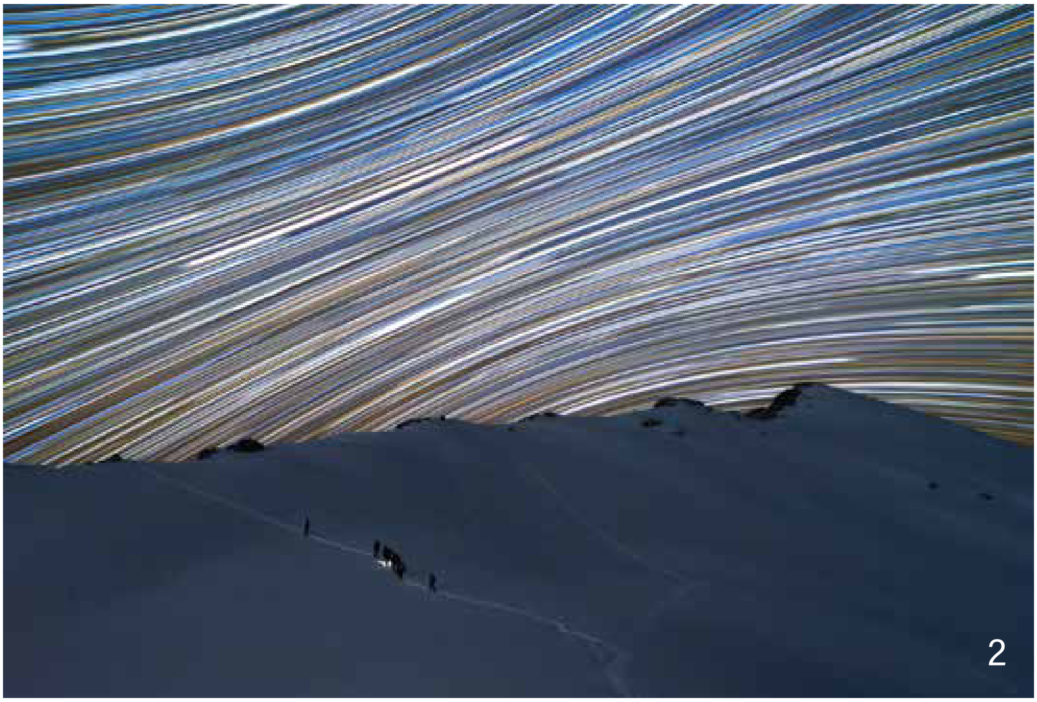
SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits



1. COMING OUT OF ITS SHELL
Astrophotographers are venturing deeper into the faint oxygen universe with narrowband OIII filters. The team behind this shot includes the trio who discovered the vast arc of emission near M31. The scene's center is dominated by the dark nebula LDN 1400 and the blue OIII arc of supernova remnant G150.3+4.5, also known as Thor's Lightning. But there is also a new find: the small oval shell at lower left around the X-ray binary star CI Camelopardalis. The object is the debris of a nova that occurred in the system between 1,500 and 2,200 years ago. ▪ ***Nicolas Martino/Yann Sainty/Team StDr***



2. TRAIL TO THE COSMOS
Trekkers ascend to the summit of Kedarkantha, a 12,500-foot (3,800 meters) peak in the Himalayas. The photographer captured the star trails with a mirrorless camera and a 14mm prime lens at f/2.8, with 30 four-minute exposures at ISO 800. ▪ ***Anushtup Roychoudhury***

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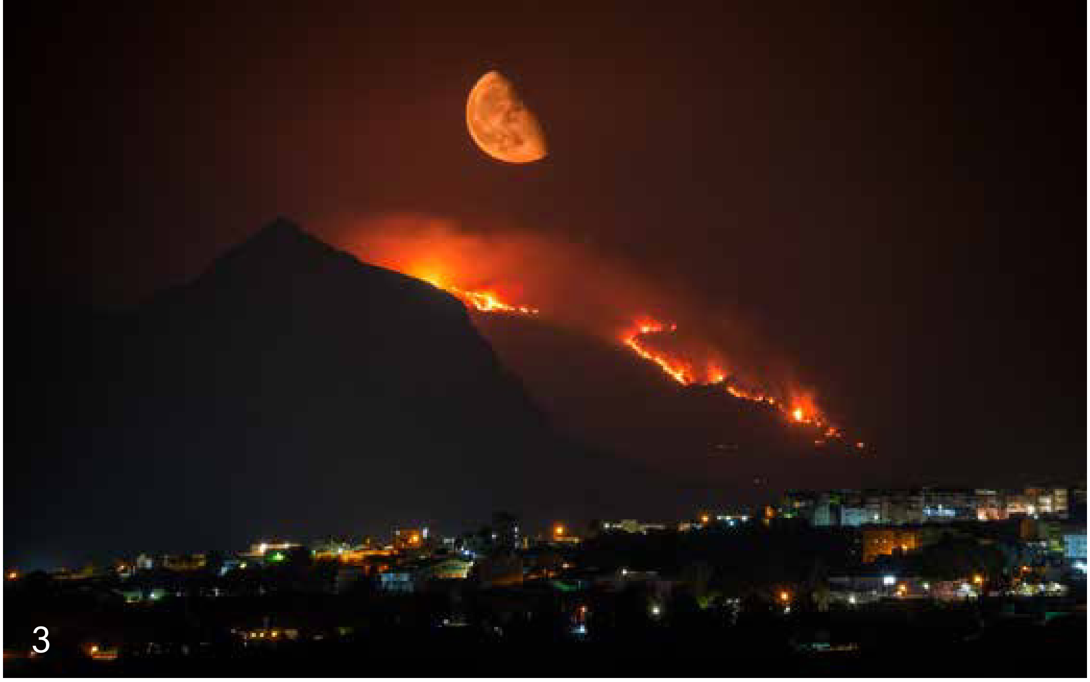
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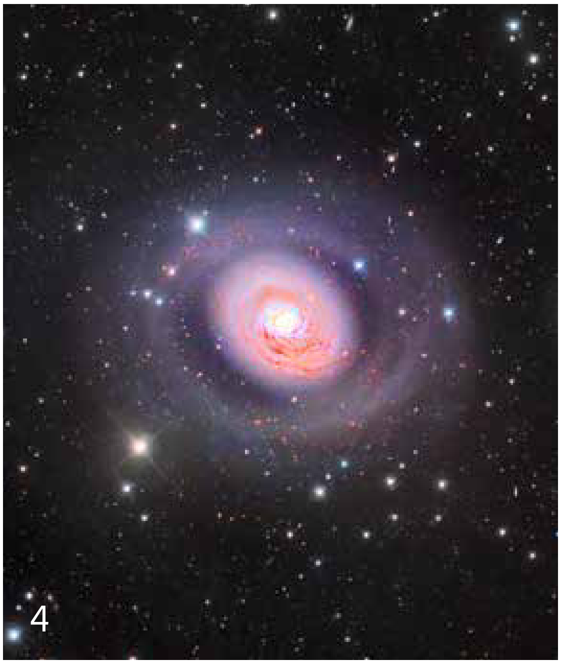
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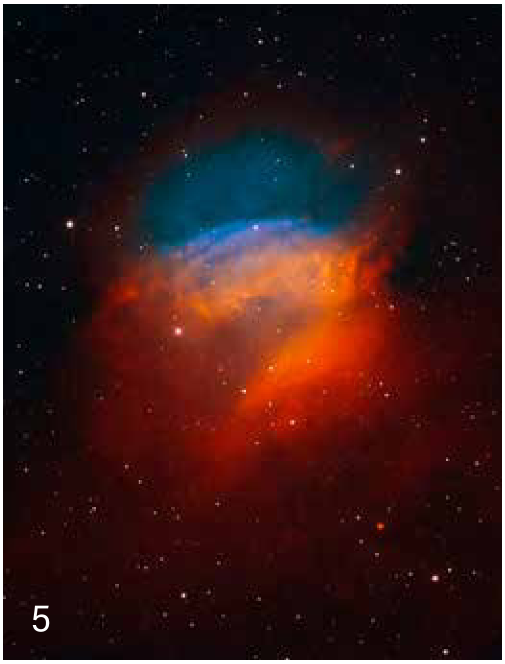
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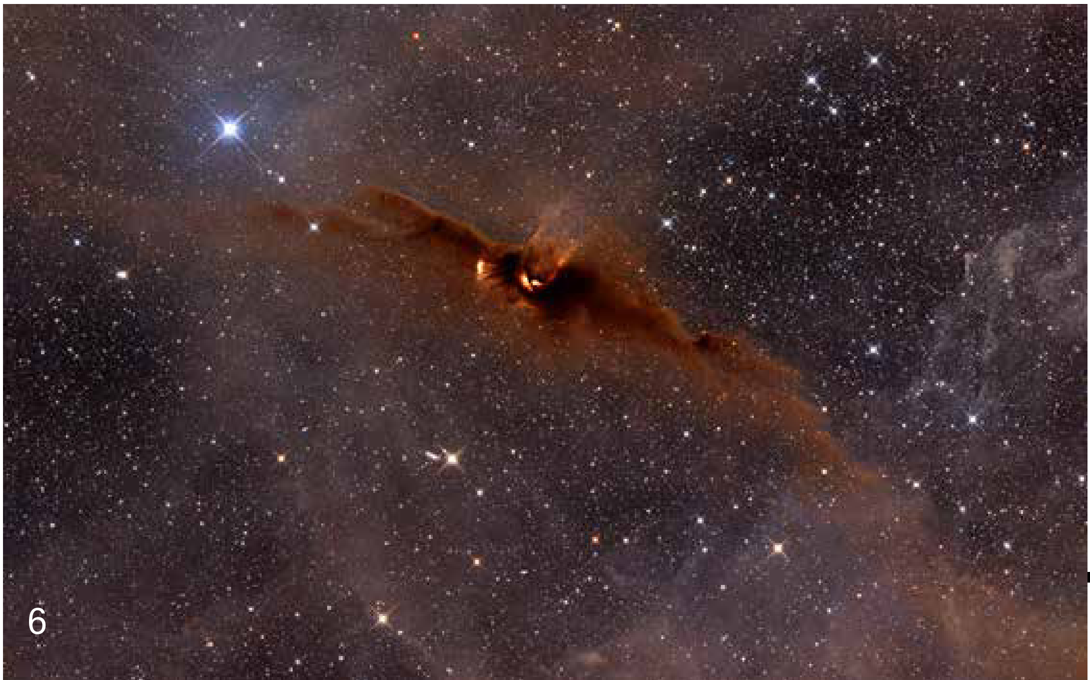
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3. SICILY ON FIRE
The Moon is reddened by haze and the glow of a raging wildfire on Sicily in July 2021. In recent years, the island has been hit by wildfires caused by record high temperatures, hot winds, and in some cases, the actions of arsonists. This image "leaves a bad taste in the mouth," the photographer says, for its juxtaposition of astronomical beauty with the drama of the fire and the consequences of human incivility. **• *Dario Giannobile***

4. A SPIRAL (REALLY)
M94 is known as the Cat's Eye Galaxy thanks to its visible structure of closed rings. However, infrared and ultraviolet images have revealed star-forming outer arms that furnish the galaxy with a more conventional spiral appearance. This LRGB image was taken with about 33 hours of exposure on a 16-inch scope. **• *Dave Doctor***

5. A MYSTERIOUS ROSE
The Valentine Rose Nebula (Sh 2–174) lies some 1,400 light-years distant in Cepheus. It was first thought to be a planetary nebula abandoned by its once-central white dwarf, GD 561 (just below the bright star near the object's pronounced blue edge). But it may also be an unrelated cloud of ambient interstellar material ionized by GD 561. This shot was taken in Hα and OIII filters with a 3.3-inch scope and a total of 33.5 hours of exposure.
• *Sara Harvey*

6. CALLING THE BATMAN
LDN 43 is also called the Cosmic Bat Nebula — and no wonder. The dark filament of dense gas is lit from within by young stars and lies about 1,400 light-years away in Ophiuchus. This LRGB image represents 4.25 hours of data taken with a 12-inch scope.
• *Gerald Rhemann*

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Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.

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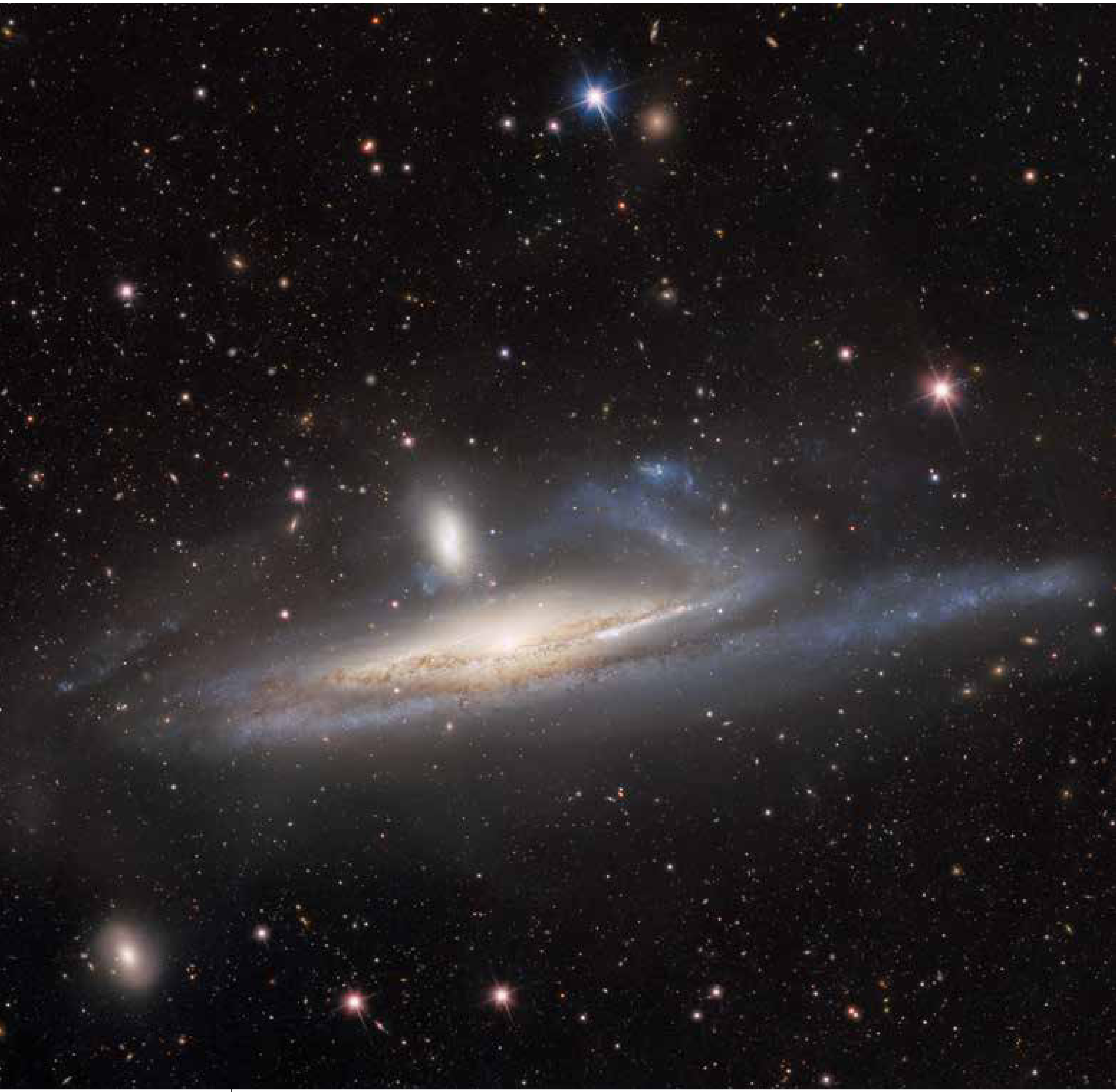

A CANNIBAL BY ANY OTHER NAME

Like a voracious shark swimming through Eridanus the River, the large spiral galaxy NGC 1532 is feasting on smaller prey. The dwarf galaxy NGC 1531 appears just above its attacker in this image taken with the Dark Energy Camera mounted on the 4-meter Victor M. Blanco Telescope at Cerro Tololo in Chile. Notice how the cosmic collision distorts the arms of the barred spiral. Tidal forces cause the arm closer to us to drop down while the more distant one arcs upward. The galactic confrontation also has sparked a flurry of star formation. The pair lies on the outskirts of the Fornax Cluster of galaxies, about 50 million light-years from Earth. CTIO/NOIRLAB/DOE/NSF/AURA/R. COLOMBARI, M. ZAMANI, AND D. DE MARTIN (NSF'S NOIRLAB)

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